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CCP-CM-020

Revision 0

CCP
Real Time Radiography
Unit #5 (RTR-5)

(Equipment #NDE-RTR-05)

Equipment Description

EFFECTIVE DATE: 05/29/2007

Mark Pearcy

PRINTED NAME

APPROVED FOR USE

RECORD OF REVISION

Revision Number	Date Approved	Description of Revision
0	05/29/2007	Initial issue.

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LIST OF ACRONYMS AND ABBREVIATIONS

AK	Acceptable Knowledge
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
CCD	Charge-Coupled Device
CCP	Central Characterization Project
CFR	Code of Federal Regulations
CM	Centimeter
dpm	Disintegration Per Minute
DOE	Department of Energy
DVR	Digital Video Recorder
ED	Equipment Description
HC	Hazard Category
HVAC	Heating, Ventilation, and Air Conditioning
kV	Kilovolt
mA	milliamps
MCS	Mobile Characterization Services
MCU	Mobile Characterization Unit
mm	Millimeter
mrem/HR	Millirem Per Hour
NDE	Nondestructive Examination
NFPA	National Fire Protection Association
PPE	Personal Protective Equipment
RCT	Radiological Control Technician
RGD	Radiation Generator Device
RTR	Real-Time Radiography
RWP	Radiation Work Permit
TRU	Transuranic
TS	Technical Supervisor
VAC	Volt Alternating Current
V	Volt
VJT	V. J. Technologies
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant
WTS	Washington TRU Solutions
WSMS	Washington Safety Management Solutions

SUMMARY

The Real-Time Radiography (RTR) Unit 5 (Equipment #NDE-RTR-05**)** is a self-contained non-intrusive assay unit, physically housed in a mobile assay container 48 feet in length by 8 feet wide, used to X-ray Transuranic (TRU) waste drums up to 85 gallons in volume. Radiography is a nondestructive qualitative and semi-quantitative technique that involves X-ray scanning of waste containers to identify and verify waste container contents. Radiography is used to examine the waste container to verify its physical form. This technique can detect prohibited items such as liquid wastes and containerized gases, which are prohibited for Waste Isolation Pilot Plant (WIPP) disposal. Radiography examination must achieve the following:

- Verify and document the physical form of each waste container
- Identify any prohibited waste in the waste container
- Confirm that the physical form of the waste matches its waste stream description (i.e., homogeneous solids, soil/gravel, or debris waste [including uncategorized metals])

The RTR-5 will provide an assay Nondestructive Examination (NDE) functionality that is designed to meet the requirements of the Waste Isolation Pilot Plant Waste Acceptance Criteria (WIPP WAC) (Department of Energy [DOE]/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*) (Ref. 1).

This Equipment Description (ED) is not an authorization basis document. It is a piece of Central Characterization Project's (CCP's) configuration management program and is intended to be used as technical information for the Host site's use when incorporating CCP's equipment into their safety basis.

This ED is a central coordinating link among the engineering design documents, the facility authorization basis, and implementing procedures. This ED does not originate requirements or basis information, but rather collects that information into a convenient usable form. The ED consolidates information about the RTR-5 system into one document.

1.0 SYSTEM DESCRIPTION

The RTR-5 is used to X-ray TRU waste containers up to 85 gallons in volume and to determine their content attributes. The RTR system is used to verify that the physical form matches the waste stream description and that the waste matrix code assigned to the waste container is consistent with Acceptable Knowledge (AK) of the waste. The system is also used to estimate waste material parameter weights and identify prohibited items in the waste container.

The RTR-5 system contains an X-ray tube. The radiographic images are produced utilizing a Radiation Generator Device (RGD) with a maximum of 320 kilovolts (kV). The high energy X-rays penetrate the steel container and transmit the image into an Image Intensifier. A high-resolution camera then records the image from the intensifier on to VHS tape and/or Digital media. Scanning provides 100% imaging of the contents of the drums and provides a non-intrusive inspection of packages containing hazardous, nuclear, and mixed waste.

There are normally only minimum radiological restrictions on occupancy on the outside of the RTR-5 trailer during X-ray operations due to the X-ray vault design. In order to keep personnel exposure levels As Low As Reasonably Achievable (ALARA), the radiographic system has been designed and constructed in accordance with American Nuclear Standards Institute (ANSI) N43.3-193-exempt shielded installed (Ref. 2) This class provides the highest degree of inherent safety because radiation protection does not depend on compliance with any operation limitations. The RTR-5 unit also has the advantage of not requiring restrictions outside the enclosure since the inherent shielding is sufficient to meet the maximum permissible dose equivalent requirements for non-controlled areas. At the operator's console, and immediately around the exterior of the trailer, the measured radiation levels are normal less than 1 millirem per hour (mrem/hr). The radiation-generating device and the drum being inspected are enclosed in a lead-shield enclosure (vault). The doors to this enclosure are fitted with redundant interlocks switches such that X-ray generation is not possible unless all doors are securely closed. The operator control station is fitted with close-circuit television monitors that provide constant visual surveillance of the shielded enclosure and conveyor area. Audible and visual alarms are provided to warn personnel near impending and actual X-ray generation.

However, some Host sites may require limited radiation posting during operations due to the drum movement and adjacent storage of TRU waste drums.

The RTR-5 layout is shown in Attachment 3, Drawings. The mobile real time system was designed to provide inspection images of dry, solid waste disposal boxes. The radiation shielded, X-ray inspection system is housed in a 48-foot long by 8-foot-5-inch wide by 13-foot-6-inch tall semi-trailer with an air suspension ride. During operations, shielded enclosures extend an additional 18-inches on one side and 36-inches on the opposition side. An elevated conveyor section extends an additional 13-feet to the rear

of the trailer to facilitate the loading and unloading of 55-gallon drums with a forklift from one side of the extension conveyor. A rotating/turntable platform is incorporated into the transport mechanism that allows the waste drums to be turned 360 degrees on the platform to complete the X-ray inspection without the assistance of a forklift. The system can inspect waste boxes of up to 6 feet in height and width, up to 10 feet in length, and up to 7,000-pounds gross weight when set up to run boxes.

Structures, Systems, and Components for the RTR-5 should be, at a minimum, classified as Balance-of-Plant to assure that proper design, operations, and maintenance requirements are assigned to provide for the health and safety of the worker and the environment and to ensure compliance with the other Host site requirements. Notwithstanding, the RTR-5 system classification is Mission-Critical (Section 2.2, DOE Standard (STD) 3024-98 [Ref. 3]).

The purpose of the NDE performed in the RTR-5 unit is to X-ray TRU waste drums up to 85 gallons in volume and determine their content attributes. The RTR system is used to verify that the physical form matches the waste stream description and that the waste matrix code assigned to the waste container is consistent with AK of the waste. The system will provide an assay functionality that is designed to meet the requirements of the WIPP WAC (DOE/WIPP-02-3122) (Ref. 1).

1.1 Facility, Major Components, and Subsystems

1.1.1 Facility

The RTR-5 is housed in a base Commercial Trailer (Class Code 10, Sub Code 6, Semi-Trailer) that allows mobile movement of the equipment to remote locations (National Fire Protection Association [NFPA] 801, Ref. 4). The RTR-5 compared to DOE standards is considered a Re-locatable Structure (Ref. 5). The RTR units are classified as V-N structure per the UBC, Type V (000) structures per NFPA 220, *Standard on Types of Building Construction* (Ref. 6). The interior finish of the control room is combustible to some extent. NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*, Section 3-5 (Ref. 4), requires that buildings used to handle and store radioactive materials have either a fire-resistive or noncombustible construction (Type I or Type II in accordance with NFPA 220). NFPA 801, Section 3-8, requires the interior finish of these buildings to be limited combustible. The design of the trailer is almost all-steel construction with wood only present on the control room sub-floor. Figure 2 provides an interior elevation view of RTR-5.

The RTR-5, compared to DOE standards, is considered a Re-locatable Structure (Ref. 5). The RTR-5 unit is divided into four sections:

- Control Room (Photographs 19 through 26)
- RTR Vault (Photographs 1 and 7)

- Equipment Bay (Loading Area) (Photographs 2, 5, 6, 12, 13, and 14)
- Unloading Bay (Back end of the trailer) (Photographs 1, 1a, and 4)

1.1.1.1 Control Room

The Control Room is located in front of the trailer unit and adjacent to the Equipment Room. There is no access from the Control Room to the Equipment Bay. The Operator must exit the Control Room and enter through the Conveyor door opening on the road side of the trailer to obtain access. The Control Room (shown in Photographs 19 through 26) includes all of the hydraulic pump and bank controllers necessary for operating the RTR System, and contains the following equipment:

- Operator's Console
- Audio/Video Subsystem. The Audio/Video subsystem is comprised of an Image Intensifier integrated closed circuit digital camera, raw video monitor, digital image processor, Digital Video Recorder (DVR), process video monitor, and video printer. Additionally, there is a closed circuit video camera and dedicated monitor for surveillance of the X-ray vault and loading area with the vault doors open.

The mechanical boundary for the RTR-5 is the drum loading and unloading conveyor. Once the drum(s) or Standard Waste Box is placed on the load and unload conveyor cart of the RTR-5, it is considered part of the RTR-5. Once the drum has been removed from the unloading conveyor of the RTR-5, it is no longer considered part of the RTR-5. The electrical boundary for the RTR-5 is the circuit breaker panel contained within the RTR-5 where external power is attached to the system and control of individual circuits within the RTR-5 is provided by the panel.

The Mobile RTR-5 System is a stand-alone, self-contained system that basically only requires electrical support for the Host site to operate.

1.1.2 Major Components

The RTR units are composed of the following major system components:

- X-Ray Vault Enclosure
- X-Ray Equipment
- Conveyor System (interior and exterior conveyors)

1.1.2.1 X-Ray Vault Enclosure

The shielded X-ray vault houses the X-ray machine, which consists of a shielded X-ray tube (lead tube head box) and an Image Intensifier box. The Image Intensifier is an

electronic device used to detect X-ray radiation and convert the energy into a visible light image viewable by the human eye. The shielding is lead, and the dimensions of the lead tube head box are 18 inch by 12 inch by 3 feet.

The X-ray vault includes access doors with radiation safety interlocks, to prevent X-ray operation with the shielded doors open. Safeguards (e.g., emergency stops) are also provided inside the X-ray vault, enabling personnel to deactivate the X-ray unit in the unlikely event that the door was closed and the unit was started while a person was inside the vault.

The doors are closed and X-ray generation is initiated as follows. The RTR-5 system contains an X-ray tube, which operates in the range of 20 kV to 320 kV and up to 1,600 watts of power is produced by the oil-insulated high-tension generators, which are located in the equipment room and are supplied to the X-ray tube via a high tension cable. X-rays are produced in the X-ray tube head and are passed through the rotating drum. The X-rays are directed at the Image Intensifier.

1.1.2.2 X-Ray Equipment

The RTR-5 system contains an X-ray tube, which operates in the range of 20 kV to 320 kV and up to 1,600 watts of power is produced by the oil-insulated high-tension generators, which are located in the equipment room, and are supplied to the X-ray tube via a high tension cable. X-rays are produced in the X-ray tube head and are passed through the rotating drum. The X-rays are directed at the Image Intensifier.

The Shell DIALA® Oil AX, used for coolant has a flash point of 2950°F and is a Class IIIB combustible liquid (NFPA 308, Section 1.7.3.1, Class IIIB—any liquid that has a flash point at or above 2,000°F [930°C]) (Ref. 7).

The coolant level of the X-ray cooler is inspected visually through the inspection window. If the coolant level is low, coolant is added as specified in the X-ray operating manual to bring the coolant level up to the correct level. This cooler is equipped with safety interlock flow over temperature.

The recording device subsystem is comprised of an Image Intensifier with integrated Charge-Coupled Device (CCD) camera, raw video monitor, precision recording devices, processed video monitor, and video printer. Additionally, there is a CCD video camera and a dedicated monitor for surveillance of the X-ray vault and loading area with the vault doors open.

1.1.2.3 Conveyor System

The conveyor system (shown in Photographs 4 through 6 and 11 through 13) includes two hydraulically and remotely controlled conveyors of approximately 8 feet in length

each, a free rolling conveyor of approximately 3 feet in length, a free rolling conveyor of approximately 1 foot in length and a chain-driven, remotely-operated pusher bar. The conveyor system is used to move, remotely, the TRU waste drums through the X-ray system. A forklift is used to place the drums on the conveyor and remove them from the conveyor following the RTR examination.

The steel gravity rollers are 2-1/2 inch by 11-gauge steel tubing, ROACH conveyor-model 251S, with flanged type bearings pressed into straight ends. The frame is formed of steel channel power painted; 4 inch by 1-1/2 inch gauge set high; 5 feet by 1-1/2 inch gauge set low. Bearings are a removable type, heavy-duty ball bearing, zinc-plated, and grease packed. Axles are 11/16 inch hex shaft, spring loaded. Capacity is 540 pounds per roller, or 3,400 pounds maximum distribution live load per 10-foot section with supports at 10-foot centers; 7,500 pounds at 5-foot centers. The maximum live load per 55-gallon container will be less than less than 1,000 pounds (safety factor of 3).

1.1.2.3.1 Lift Table (Drum Manipulator)

The hydraulically controlled lift table (drum manipulator), located inside the X-ray vault, is remotely operated to allow movement of the entire drum through the X-ray field. The drum is pushed onto the drum manipulator by the pusher bar. The manipulator can rotate the drum 360 degrees clockwise and counter-clockwise, raise or lower the drum, and shift the drum from side to side.

1.1.2.3.2 Chain Driven Pusher Bar

The chain-driven, remotely-operated pusher bar is used to move the drum from the entry 8-foot section of conveyor onto the 3-foot section of free rolling conveyor and then onto the drum manipulator for drum RTR examination. The pusher bar can only be operated when the X-ray vault doors have been completely opened. Following the drum RTR examination, and only after the X-ray vault doors have again completely opened, the pusher bar is remotely deployed to push the drum onto the 1-foot free-rolling conveyor and then onto the exit 8-foot section of conveyor.

1.1.3 Subsystems

1.1.3.1 Civil and Structural

The RTR-5 is classified as a Type V (000) structure per NFPA 220, *Standard on Types of Building Construction* (Ref. 6), NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*, Section 3-5 (Ref. 4), requires buildings used to handle and store radioactive materials to have either a fire-resistive or noncombustible construction (Type I or Type II in accordance with NFPA 220, Ref. 6). NFPA 801, Section 3-8, requires the interior finish of these buildings to be limited combustible. The interior finish for the RTR-5 is combustible to some extent as discussed below.

The exterior walls of the unit are steel, over a steel stud frame of a standard trailer truck. The Operator Control Room ceiling is composed of steel (shell of the trailer) with interior steel studs covered by vinyl. A drop plastic lighting panel system is connected to the steel studs of the roof of the trailer. The Operator Control Room floor is vinyl tile over plywood sub-flooring, which is placed over the steel frame of the trailer structure. The Vault consists of a lead-lined steel-framed vault, which is connected to the steel floor of the trailer (the Vault is not part of the trailer structure walls, floor, or ceiling, but is positioned within the trailer). The Loading Area consists of steel walls and ceilings. The floor is covered with steel plates over the structural frame of the trailer.

Figure 1 (shown in Attachment 3) shows the basic layout of the RTR-5 unit.

1.1.3.1.1 Operator Control Room

Walls: The exterior walls of the unit are steel, over a steel stud frame of a standard trailer truck.

Ceiling: The Operator Control Room ceiling is composed of steel (shell of the trailer) with interior steel studs covered by vinyl. A drop plastic lighting panel system is connected to the steel studs of the roof of the trailer

Floor: The Operator Control Room floor is vinyl tile over plywood sub-flooring, which is placed over the steel frame of the trailer structure.

1.1.3.1.2 Vault Enclosure

Walls: The vault consists of a lead-lined steel-framed vault, which is connected to the steel floor of the trailer (the vault is not part of the trailer structure walls, floor, or ceiling, but is positioned within the trailer).

Floor: The floor is covered with steel plates over the structural frame of the trailer.

1.1.3.1.3 Trailer Physical Dimensions

Length: 48 feet
Width: 8 feet
Height: 12 feet
Weight: 75,000 pounds

1.1.3.2 Mechanical and Material

A Heating Ventilation and Air Conditioning (HVAC) unit (shown in Photograph 15) is provided strictly for the purpose of comfort of the operators, who are located in the Control Room. There are no heating or cooling units provided for radiological

operations in the X-ray vault or Equipment Bay (drum loading areas). Overhead electrical heaters are located in the equipment room and vault.

1.1.3.3 Chemical and Process

The WIPP WAC requires that TRU waste not contain explosives, corrosives, or compressed gases. Non-radionuclide pyrophoric materials are prohibited at WIPP. Additionally, flammable Volatile Organic Compounds are restricted to less than 500 parts per million within payload container headspace (a level that would not challenge integrity of the container). Polychlorinated biphenyls are also limited to less than 50 parts per million. Therefore, chemical hazards are not expected to result in significant consequences or significantly contribute to accidents involving radiological materials. Hazardous materials are present in less than reportable quantities or threshold planning quantities.

Based on the chemical inventory (chemicals are limited to small quantities used in maintenance or contamination in mixed TRU waste), it is not anticipated that threshold quantities of the Occupational Safety and Health Administration *Process Safety Management Standard* (Title 29, Code of Federal Regulations [CFR], Part 1910.119) would be exceeded (Ref. 8).

There are no compressed gases used in this process.

Generators (shown in Photograph 8) ensure that TRU waste is not in free-liquid form, that minor residual liquids remaining in well drained internal containers (e.g., bottles, cans) do not exceed 1-inch (2.5 centimeters [cm]) in the bottom of any container and that the total liquid in the waste package does not exceed 1 volume percent. There are no compressed gases used in this process.

1.1.3.4 Electrical Power

The RTR-5 is a stand-alone, self-contained system that requires electrical power to operate. Refer to the Operating procedure (Central Characterization Project [CCP] CCP-TP-119, *CCP Operating the Real Time Radiography [RTR] System # 5* [Ref. 19]) for a detailed description of the Operational Set-up and Checkout procedures.

- Electrical supply for RTR-5: 220 volts (V), 125 amps, three-phase

The electrical power feed panel is located on the outside wall inside the control room (shown in Photographs 17 and 18). All RTR equipment is designed and installed in accordance with the minimum standards of the National Electric Code and NFPA 70, *National Electrical Code* (Ref. 9) [e.g., enclosure power interlocks, four-prong plugs, breakers, fuses, ground-fault circuit interrupt, etc.].

The distribution panel is mounted inside the operator control room.

The electrical boundary for RTR-5 is the circuit breaker panel contained within the RTR where external power is attached to the system and control of individual circuits within the RTR is provided by the panel.

1.1.3.4.1 Procedure for Power-up

The following pre-start operations should be performed before powering up the RTR-5:

- Trailer doors - Unlock and open the rear trailer doors. Be sure to secure the doors with holding brackets.
- Conveyor Tracks - Visually check the conveyor tracks to make sure they are free from obstructions.
- Control Room - Enter the control room. At the Operators Bench Board, power on the system using the Mushroom button.

Lighting

There are fluorescent light fixtures controlled by light switches inside the operator control room access door. In addition, batteries are provided for emergency lighting.

Exit Signs

Illuminated exit signs are provided over the personnel access doors. Battery backup is provided for these signs.

Emergency Lighting

Emergency lighting inside the structure is battery powered and come on when power fails to the service panel.

Outlets

Duplex receptacles are positioned along each wall (120 Volt Alternating Current [VAC], 20 amp). Receptacles are spaced no more than 10 feet apart and each wall shall have at least two receptacles. Two receptacles are on a dedicated 20-amp circuit for use at the personnel work area desk. All receptacles are ground fault circuit interrupter protected.

Electrical devices, such as receptacles and light switches are suitable for industrial service and have at least a 20-amp rating. All devices are Underwriters Laboratory listed.

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Grounding Lugs

Ground lugs are provided on the outside of the trailer.

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2.0 DESIGN REQUIREMENTS

2.1 Specific Requirements

While quantitative design requirements have not been identified for the RTR-5, the system must be capable of assuring that fissionable material in its inspected drums does not exceed that permitted by the WIPP WAC (Ref. 1). The facility at which the RTR-5 operates must also establish that the system, in its site-specific implementation, meets 10 CFR 830 (Ref. 10), 10 CFR 835 (Ref. 11), and other requirements applicable to that site.

2.2 Codes and Standards

While codes and standards have not been identified as design requirements, a number of codes and standards have been used in the “as-built” system and are identified, where applicable.

3.0 OPERATIONAL INFORMATION

3.1 System Control Features

3.1.1 Manual Controls

The following sections describe the functions of some of the various switches located on the control panel.

3.1.1.1 Emergency Shutdown Devices

RTR-5 is equipped with emergency shutdowns/overrides at the operator console (i.e., red mushroom button located on the operator's bench board shown in Photograph 22) and on the inside of X-ray vault. Once activated, all systems stop, including any mechanical movement of the motorized conveyors (i.e., inside and outside conveyors).

3.1.1.1.1 Warning Lights

Audible and visible warning signals are provided for X-ray production. These signals include the following:

- Pre-warning signals 20 seconds before X-ray generation is started
- Warning signals when X-ray generation starts and is on
- Warning signals associated with X-ray production include the following:
  - Two illuminated "X-RAY ON" signs located outside the shielded vault doors; one (X-20) over the vault access door inside the RTR Operator Area and the second (X-20) over the vault load door facing the enclosure
  - One warning light stack with an amber (X-19) and a red light (X-20), each visible for 360 degrees, is located on the outside of the shielded vault on the roof of the enclosure
  - A second warning light stack with an amber (X-19) and a red light (X-20) is located inside the shielded vault. In addition, an audible alarm (X-19) is included with this warning light stack

When the green START button on the control console is pressed to initiate X-rays, the pre-warning time begins and the pre-warning annunciators are activated:

- The DELAY lamp on the RGD X-ray controller (Pantak) illuminates
- An audible alarm sounds (X-19)
- The amber warning lights are illuminated (X-19)

Pre-warning time is adjustable. For this application, it is set to 20 seconds in compliance with ANSI N43.3, Section 5.1.5.1 (Ref. 2). After the end of the pre-warning time, high voltage is transferred to the X-ray tube, the pre-warning signals stop, and the radiation warning signals start:

- X-rays ON warning lamp on the RGD X-ray controller (Pantak) flashes
- Red warning lights flash (X-20)
- X-RAY ON signs are illuminated (X-20)

All X-ray warning signals are operated with 110 VAC. They are controlled by the RGD X-ray controller (Pantak) via two relays in the main control junction box. The pre-warning relay is connected in the safety interlock junction box to Terminal 10, *X-rays Delay Lamp*. The X-ray on relay is connected to Terminal 9, *X-rays On Lamp*. Terminal 11, *Lamp (N)* is used for the neutral connections of both relays.

3.1.1.2 Warning Signals – Conveyor System

The conveyor system warning signals are not tied to any X-ray generation or X-ray safety interlocks. These warning signals are described briefly to demonstrate the additional safety measures associated with drum X-ray operation. Audible and visible warning signals are provided for conveyor motion:

- Flashing green lights indicate that the conveyor system is powered on.
- Steady green lights indicate that the cart is at rest or is inside the shielded vault.
- Flashing amber lights indicate a 5-second delay before conveyor or cart movement begins outside the shielded vault.
- A warning horn signals the beginning of the 5-second delay period prior to conveyor or cart movement outside the shielded vault.

3.1.2 Fire Protection

The RTR-5 is equipped with several smoke detectors. These detectors can be linked to Host site fire dispatch systems. Fire extinguishers (shown in Photograph 26) are located in the loading area and Control Room.

3.1.3 Nuclear Criticality Safety

Per DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports* (Ref. 12), criticality hazards are not a concern for Hazard Category (HC)-III facilities. Isotope inventory thresholds for HC-III facilities, established in Attachment 1 of the referenced DOE standard, preclude the potential for a criticality event (Ref. 12).

3.1.3.1 Radiation and Other Hazards

The RTR-5 system includes the X-ray machine and the equipment necessary to operate the machine. The X-ray machine consists of a shielded X-ray tube, located within the shielded X-ray vault, which operates in the range of 20 kV to 320 kV. This process can detect prohibited items such as liquid wastes and containerized gases, which are prohibited for WIPP disposal. The prohibition of liquids and containerized gases prevents the shipment of corrosive, ignitable, or reactive wastes.

The Personal Protective Equipment (PPE) for normal operations are leather gloves when handling drums, safety shoes, and thermoluminescent dosimeters. Additional PPE may be used, such as work coveralls and safety glasses. PPE for abnormal conditions shall be specified by the Radiological Control Technician (RCT) or addressed in the Host site Radiological Work Permit (RWP). PPE is worn before starting any operations. Workers who will be working in a radiation area must have read and signed the applicable Host site RWP and received orientation to applicable work package.

There are normally only minimum personnel radiological restrictions on the outside of the RTR-5 trailer during X-ray operations. However, some Host sites may require limited radiation posting during operations.

The RTR-5 system contains an X-ray tube that operates in the range of 20 kV to 320 kV, and up to 1,600 watts of power is produced by the oil-insulated high-tension generators, which are located in the equipment room, and is supplied to the X-ray tube through a high-tension cable.

3.1.3.2 Process Evaluations

A criticality evaluation of the individual equipment/processes/facilities is not needed due to the insufficient inventory of fissionable material mandated by HC-III classification, provided an Inventory Control Program is in place.

The minimum theoretical quantity of Pu-239 necessary for criticality, assuming favorable configuration, moderation, and reflection, is 450 grams (ANSI 1998). Although a package might contain material favorable for moderation or reflection, inadvertent repackaging into a critical configuration is very improbable due to the low inventory of fissile material and the waste form geometry.

The RTR-5 processes one drum at a time. WIPP WAC criteria and AK evaluations preclud any TRU waste drum(s) being processed to the RTR-5 for analysis that would challenge criticality safety. DOE facilities where this equipment may operate is normally operated under a Safety Analysis or documented safety basis documents, which establish bound limits and inventory controls for TRU waste drums.

3.1.3.3 Waste Drum Contamination on Surface

Drum handling and radiological control requirements are determined by the external radiation dose rate. Survey records are used to determine the sum of gamma and neutron dose rates at 30 cm from the drum surface. External radiation at 30 cm from drum surface should be less than 200 mrem/hr. Drum staging areas and the perimeter of the RTR-5 trailer are normally posted and controlled as a Radiation Area during operations. The drum can be accepted for examination when the above conditions are met. When the external radiation at 30 cm from the drum surface is greater than 200 mrem/hr, the RCT is notified that a special posting is required.

3.1.3.3.1 Alpha Contamination on Drum Surface

Waste drums are not acceptable if removable alpha contamination on the drum surface exceeds 20 disintegrations per minute (dpm)/100 cm^2.

3.1.3.3.2 Beta Contamination on Drum Surface

Waste drums are not acceptable if removable Beta contamination on the drum surface exceeds 200-dpm/100 cm^2.

3.1.3.4 Waste Drum Dose Rate Limits

Drum handling and radiological control requirements are determined by the external radiation dose rate. The external radiation surface dose rate of individual payload containers shall be less than, or equal to, the limits specified in CCP-PO-003, *CCP Transuranic Authorized Methods for Payload Control* (Ref. 16), Table 3.2-1, Maximum Surface Dose Rate Limits. A Host site RCT measures the surface dose rates of the individual payload containers in accordance with site radiological survey procedures and documents the survey information on the container survey reports.

3.1.4 ALARA

Radiological posting is used to alert personnel to the presence of radiation and radioactive materials and to aid in minimizing exposures and preventing the spread of contamination. Radiological posting are installed before work begins and updated periodically when changes in radiological conditions occur or are expected.

The area of operation around the characterization equipment may be posted as Controlled Area that bounds a larger area of operations around the equipment. Each access point to a controlled area (as defined at Sec. 835.2) shall be posted whenever radiological areas or radioactive material areas exist in the area. Individuals who enter only controlled areas without entering radiological areas or radioactive material areas are not expected to receive a total effective dose equivalent of more than 0.1 rem

(0.001 sievert) in a year. Signs used for this purpose may be selected by the contractor to avoid conflict with local security requirements (Ref. 11).

Routine contamination surveys should be performed of the immediate area outside of the RTR-5 unit.

3.1.4.1 Radiological Posting

Radiological areas are posted with signs containing the standard radiation symbol with black or magenta lettering on yellow background [835.601 (b) and 835.601 (c)] [1]. The radiological postings are displayed to signify the actual or potential radiological conditions of the area. Postings are maintained in a legible condition and updated based on the most recent survey results. Signs and labels shall contain the standard radiation-warning trefoil colored magenta or black on yellow background. Lettering shall be either magenta or black. Magenta is the preferred color over black [835.601 (a)]. Unless circumstances do not permit, the standard radiation-warning trefoil should be oriented with one blade downward and centered on the vertical axis. Lettering should not be superimposed on the standard radiation-warning trefoil (ANSI 1989). The size of the lettering used on the sign should not detract from the clarity of the standard radiation-warning trefoil. (DOE G 441.1-10, *Posting and Labeling for Radiological Control Guide for use with* 10 CFR 835*, Occupational Radiation Protection* [Ref. 11]).

3.1.4.2 Radiological Posting Areas

Radiological posting are verified daily before entering the RTR-5. If the posting is missing, dislodged, or believed to be incorrect, the Technical Supervisor (TS) and the RCT shall be notified. The Operator shall not enter until the TS and RCT review the posting and approve entry.

Physical barriers are used to designate the posted boundaries, when required by the RWP. All work conducted in these areas is controlled by the approved Host site RWPs. All physical barriers shall be placed so that they are clearly visible from all directions and various elevations. They should not be easily walked over or under, except at identified access points. Rope, tape, chain, and similar barriers used to designate the boundaries of posted areas should be yellow and magenta in color. No control(s) shall be installed at any radiological area exit that would prevent rapid evacuation of personnel under emergency conditions [835.501 (e)][1] (Ref. 11).

External posting around the equipment is determined and controlled by the Host site RWP and ALARA program requirements. Postings should be maintained in a legible condition and updated based upon the results of the most recent surveys.

- Posting is located near the door in such a way so that when the door is opened or closed the posting remains visible. Signs shall be conspicuously posted, clearly worded, and where appropriate, may include radiological control instructions [835.601 (d)] [1] (Ref. 11).
- The Host site establishes controlled areas normally around the RTR-5. The posting serves to warn individuals that they are entering areas that, because of the presence of radiological areas and/or Radiation Material Areas, are controlled for radiation protection purposes. The Radiation Material Areas and radiological areas are established within the controlled area to provide warning of specific hazards that may require individual protection action for safe entry and egress.
- High energy X-rays are the only source of radiation during the operating of the X-ray equipment. When the X-ray equipment is not energized (X-ray in process), there is no radiological concern.

Radiological Controls: The Host site will provide Radiological Control Inspectors to support all drum handling, characterization, and loading activities. Appropriate signs, barricades, and postings are considered part of radiological controls.

3.1.5 Industrial Hazards

3.1.5.1 Common Hazards

A Process Hazard Review was performed to analyze hazards associated with the RTR systems. The most common hazards associated with RTR systems are: high energy X-rays, high voltages, and pinch points. These hazards are addressed in safety training for personnel who operator the system. See, CCP-HSP-009, *CCP RTR Health and Safety Plan*, for additional information (Ref. 15).

3.1.5.2 Additional Precautions and Limitations

Prior to certified operation, the RTR-5 TS ensures that the operator has met the requirements for test and training drums as defined in *CCP-TP-028, CCP Radiographic Test and Training Drum Requirements* (Ref. 17).

Background radiation levels from adjacent storage areas or when used near other NDE/Nondestructive Assay mobile trailers must be less than 2.5 mrem/hr, so as not to adversely affect the measurements taken in this trailer.

- High energy X-rays, high voltages, and pinch point are potential hazards associated with the RTR-5 system. These hazards are addressed in safety training for personnel who operate the RTR-5 system.
- After the X-ray "Start" button is depressed, an amber beacon located inside the vault chamber is illuminated 20 seconds warning of X-ray generation is to begin. The red beacon illuminates.
- A video camera maintains surveillance of the vault at all times.
- X-ray exposure cannot be re-activated after the emergency stop button is depressed until the emergency button is reset and the fault message is cleared at the X-ray controller.
- Do not attempt to open the vault doors when X-ray system is in operations.
- Do not leave the system operating unattended at anytime.
- RTR-5 doors are locked when system is unattended.

The system includes the following interlocks and safety features:

- X-ray exposure cannot be initiated until the vault doors are in the closed position.
- If the CCP-TP-045, *CCP #5 RTR Radiography Inspection Operating Procedure*, (Ref. 18) can not be implemented as written, RTR personnel shall notify appropriate supervision.
- If it is determined that a portion of the work can not be accomplished as described in the CCP-TP-045, *CCP #5 RTR Radiography Inspection Operating Procedure* (Ref. 18) or would result in an undesirable situation, work shall be stopped. Work will not be resumed until the procedure is modified or replaced by a new document that reflects the current work practice.
- Employees may use copies of CCP-TP-045, *CCP #5 RTR Radiography Inspection Operating Procedure* (Ref. 18), printed from the controlled document file, however, employees are responsible for assuring that the correct revision of this procedure is used.
- The system is equipped with ALARM X-ray safety system.
- After the X-RAY ON button is depressed, an amber beacon located inside the chamber is illuminated and an alarm sounds for 10 to 20 seconds, as a warning that X-ray production/inspection is to begin.
- Following the 10 to 20 second delay, X-ray exposure begins. The red beacon inside the vault, the X-ray sign on the backside of the vault, and the red indicator on the X-ray control console are illuminated.
- Anyone left inside the vault during X-ray initiation can stop X-ray exposure by depressing the red EMERGENCY STOP button located on the ALARM system box.

- X-ray exposure cannot be re-activated after the STOP button is depressed until the ALARM system inside the vault is reset.
- When approaching the radiation source, use a suitable operable calibrated survey instrument to verify that the X-ray tube has been de-energized and the X-RAY ON button pushed.

3.1.6 Operating Environment and Natural Phenomena

The characterization units and associated equipment were not designed and built to DOE Natural Phenomena Hazard standards. The associated equipment is not seismically qualified. The RTR-5 structure does not perform an emergency function and is not Safety Significant or Safety Class.

3.1.7 Instrumentation and Control

3.1.7.1 Security/Television Monitoring Systems

The Security/Television Monitoring System includes three strategically placed security cameras (one in the equipment area, one in the X-ray vault, and one in the exit area), three black and white security monitors (located in the control room), one 12-inch black and white television monitor (located in the control room), and a video system for recording the images (located in the control room).

The Image Intensifier, located in the X-ray vault, converts the X-ray image into a visible-light image. The visible-light image is detected by a high-resolution CCD camera and the image is displayed on a television monitor.

The video system includes a DVR, an alphanumeric character generating drive for text narrative, and an audio track for audio narrative.

To produce a clear picture of various thickness materials, the X-ray may be varied from 20 to 320 kV and 0 to 5 milliamps (mA). The system is also equipped with a large and small focal spot for increased resolution.

Closed-circuit cameras are provided to observe operations in the shielded vault and enclosure rooms. All cameras, except for the bar code camera, are used by the RTR operator to assure that all personnel are clear before X-ray operations commence, and to observe the mechanical systems during operation. The four cameras provided include the following:

- *Vault Camera 1:* Vault Camera 1 is located adjacent to the vault access door. The camera is equipped with pan/tilt/zoom capability and is remotely controlled from the operator's console.

- *Enclosure Camera 1:* Enclosure Camera 1 is located in the enclosure near the enclosure loading door.
- *Vault Camera 2:* Vault Camera 2 is located in the enclosure near the enclosure unloading door.
- *Bar Code Camera:* The bar code camera is located at the bar code station within the vault and enables the operator to read the bar code number on a drum.

Camera images are displayed on the surveillance monitor mounted above the control console. The surveillance monitor is selectable and may display any of the four camera images, automatically switch from one image to another, or display all four camera images at once (quad display).

The operating procedure will require that the operator visually check the vault (via the television camera) to assure that it is free of all personnel prior to operation of the X-ray generator after loading door opening in order to comply with ANSI N43.3 Sect. 9.3.1.4 (Ref. 2) (see Appendix B for instructions on the Audio/Video setup).

3.2 REFERENCES

1. DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, NM

2. ANSI N43.3, *Installations Using Non-Medical X-ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV*

3. DOE-STD-3024-98, *Content Of System Design Descriptions*

4. NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*, National Fire Protection Association, Quincy, MA

5. DOE-STD-1088-95, *Fire Protection for Relocatable Structures*

6. NFPA 220, *Standard on Types of Building Construction*, National Fire Protection Association, Quincy, MA

7. *Shell Safety Data for X-ray System Oil Tube head coolant* (MSDS Number 60.030.9)

8. CFR 29, *Occupational Safety and Health Standards, Subsection 1910.119, Hazardous Materials*, Code of Federal Regulations, U.S. Department of Energy, Washington, DC

9. NFPA 70, *National Electrical Code*, National Fire Protection Association, Quincy, MA

10. Title 10 Energy, Part 830, *Nuclear Safety Management, Code of Federal Regulations,* U.S. Department of Energy, Washington, DC

11. Title 10 Energy, Part 835 *Occupational Radiation Protection*, Code of Federal Regulations, U.S. Department of Energy, Washington, DC

12. DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*

13. WSMS-TR-06-0034, *Process Hazard Review for RTR Systems*

14. CCP-CM-001*, CCP Equipment Change Authorization and Documentation*

15. CCP-HSP-009, *CCP RTR Health and Safety Plan*

16. CCP-PO-003, *CCP Transuranic Authorized Methods for Payload Control (CCP CH-TRAMPAC)*

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17. CCP-TP-028, *CCP Radiographic Test and Training Drum Requirements*

18. CCP-TP-045, *CCP RTR #5 Radiography Inspection Operating Procedure*

19. CCP-TP-119, *CCP Operating the Real Time Radiography (RTR) System #5*

20. CCP-TP-140, *CCP Equipment Maintenance*

Attachment 1 – Equipment Setup Requirements

Central Characterization Project (CCP)

Mobile Characterization Unit (MCU) Installation Specifications

Equipment: Real Time Radiography Unit (NDE-RTR-05)

Summary: Table A contains information regarding general site installation and preparation information for the RTR-5 MCU.

Table A Installation Specifications	
Weight	Approx. weight of trailer – 75,000 pounds
Primary Electrical Requirements (including overcurrent protection and grounding)	The RTR-5 is a stand-alone, self-contained system that requires electrical power to operate. Refer to the Operating procedure (CCP-TP-119, *CCP Operating the Real Time Radiography [RTR] System # 5* [Ref. 19]) for a detailed description of the Operational Set-up and Checkout procedures. Electrical supply for RTR-5: 220V, 125 amps, three-phase The electrical power feed panel is located on the outside wall inside the control room (shown in Photographs 17 and 18). All RTR equipment is designed and installed in accordance with the minimum standards of the National Electric Code and NFPA 70, *National Electrical Code* (Ref. 9) [e.g., enclosure power interlocks, four-prong plugs, breakers, fuses, ground-fault circuit interrupt, etc.]. The distribution panel is mounted inside the operator control room. The electrical boundary for RTR-5 is the circuit breaker panel contained within the RTR where external power is attached to the system and control of individual circuits within the RTR is provided by the panel.
Fire Suppression	The RTR-5 is equipped with several smoke detectors. These detectors can be linked to Host site fire dispatch systems. Fire extinguishers (shown in Photograph 26) are located in the loading area and Control Room.
Communication	Two phone lines and two Ethernet data lines are located in the control room.

Attachment 1 – Equipment Setup Requirements (Continued)

Footprint	Table B lists the minimum required area for the RTR-5 trailer to operate with adequate area for forklift support.
Leveling	The Host site shall provide a harden surface (concrete floor, concrete pads, asphalt, or dirt or gravel can also be considered or other suitable surfaces to maintain the trailer load). The vault doors are very heavy; therefore, the trailer must be as level as possible to assist in the manual closing of the vault doors and to avoid any industrial accidents. The trailer should be parked in an area where the following is taken into consideration: a) The front of the trailer is at a level equal to, or high than, the rear of the trailer. If the front is pitch too low, the stairs will not function and closing the heavy vault doors could result in a safety hazard. The pitch of the surface should be no more than 4 inches over the 8-foot width of the landing pads. The grade of the surface should be no more than 6 inches over the span between the leveling jacks. b) Once the trailer is properly located, chock the wheels and unhook the trailer. When lowering the four landing gears, install a minimum of 12 inch square by 1/2 inch think steel plate or hard wood under the four pads. Position the jack spacers as necessary and lower all four manual leveling legs until they touch the ground or spacers. c) Disengage the tractor from the trailer. d) Utilize a carpenter's level to manually level the trailer by raising or lowering each jack. Use appropriate sized shims (steel or hardwood) under the front and back jacks as required. The goal is to have the trailer floor area as level as possible to support operations. e) Remove the office stairs and handrail assemblies from the storage portion of the trailer. f) Mount the stair assembly to the trailer attach points and install and pin handrails in place. Level the stairs, as required. g) **NOTE:** Due to location of the rear tandem near the back of the trailer, the turning radius for maneuvering the trailer into position will be approximately 40 feet (12.2m).

Attachment 1 – Equipment Setup Requirements (Continued)

Separation Distances	Structure shall not be placed over control valves, access ways to underground utilities, utility corridors, gas mains, or water mains. Exception: structure may be placed above those utility lines that service the structure itself. The structure shall not be placed beneath vital power lines or lines over 600 volts such that fire in the structure could damage the lines. Such structure should also not be placed under other vital utilities, such as communication cables and inerting gas lines, unless the structure is protected by an automatic fire suppression system. Service conduct clearances and disconnects should be in accordance with NFPA 70. The structure should not be placed closer than 50 feet (15.2 m) to fire hydrant. At least one fire hydrant supplied by an adequate and reliable water distribution system should be located so that it does not require more than 300 feet (91.4 m) of fire hose to reach any exterior portion of the structure. However, since the structure is less than 5,000 square feet in floor area, and the Maximum Possible Loss is less than $1 million dollars, this structure can be exempted from these requirements. Structure should not be closer than 50 feet to a fire hydrant.
Emergency Egress	Structure should not be located where they impede or otherwise hinder personnel egress or ingress to, or within, other facilities or structures. Structure should be located where they impede or otherwise hinder the access of emergency response vehicles to other facilities or structures. Structures should be not be placed inside permanent facilities that do not have sprinkle unless a fire hazards analysis demonstrates that there is no significant increase in fire risk to the facility. Structures that are placed inside permanent facilities should be protected with the same level of fire protection as provided for the permanent facility. Structure shall be placed so emergency vehicles can operate within 100 feet of the structure. The space between the structure and the road should be free of natural obstructions that would prevent or severely restrict access by emergency responders. Security barriers should be designed in a manner that permits emergency access. Landscaping and similar non-essential obstructions should not restrict emergency access.

Attachment 1 – Equipment Setup Requirements (Continued)

Emergency Egress (Cont.)	Site location for structure should be evaluated for wildland fire Site exposures.

The following table lists the minimum required area for the RTR-5 trailer but also insures that there is adequate area to maneuver forklifts for the loading and unloading of the drums.

Table B. Minimum Required Area

Conveyors Used	Road Side (Load Side)	Trailer (Length by Width)	Curb Side (Unload Side)	Total (Length by Width)
20 feet both sides	20 feet	48 feet long 8 feet 6-3/8 inches wide	20 feet	48 feet long 48 feet 6-3/8 inches wide
10 feet both sides	10 feet	48 feet long 8 feet 6-3/8 inches wide	10 feet	48 feet long 28 feet 6-3/8 inches wide
10 feet road side	10 feet	48 feet long 8 feet 6-3/8 inches wide	7 feet 7 inches (Stairs)	48 feet long 26 feet 1-3/8 inches wide

Attachment 2 – Shielding Calculations

V. J. Technologies (VJT) Mobile RTR Trailer Shielding Calculation

D.1 Radiation Calculation Summary

VJT has carried out shielding calculations using the methodology normally used in the design of all VJT systems, to verify the reconfigured trailer shielding design. This is described in the "Initial Calculation Assessment." The calculation process used empirical charts that are unpublished but have been proven in design over many years and are generally conservative. The VJT shielding is generally less thick than the calculations indicate as being required. However, past VJT experience has demonstrated that less shielding than the calculated values still meets the 0.5 mrem/hour dose limit at any point five centimeters outside the external surfaces (as specified in Section 4.1.1 of ANSI N43.3 for an Exempt Shielded Installation). A second set of "Check Calculations" has been carried out to evaluate the shielding with respect to the ANSI N43.3 Annex D guidelines. This methodology also addresses the uncertainties in dimensional accuracy and includes an assessment of shielding, beam filtering and scattering effects not covered in the Initial Calculations. The uncertainties in calculated shielding requirements are compared with the uncertainties in actual shielding implemented. These calculations show an area of overlap of these uncertainties, which are then checked by a radiation survey carried out by an independent expert.

D.1.1 Initial Calculation Assessment

The lead shield thickness requirements as determined from the empirical charts may be conservative because:

- The assembled RTR system provided by VJT has some additional shielding components, structures, and materials not taken into account in this determination. An example of this is the internal lead and nickel shields on the image intensifier housing/enclosure and attenuation of the primary X-ray beam provided by the image intensifier phosphor screens.
- The additional lead thickness determined from the empirical charts was for a dose rate of 0.25 mrem/hour, which is half of the 0.5 mrem/hour dose rate. However, the additional empirical chart data for 0.25 and 0.75 mrem/hour dose rates shows the change in lead requirements over this range is on the order of 5mm (0.2-inch) and not overly significant.
- A 3 mm thick copper filter is fitted to the collimator. The primary beam passes through this filter, which reduces the lower energy X-rays.

Attachment 2 – Shielding Calculations (Continued)

In conclusion, the use of empirical data charts for a design basis estimate demonstrated that some additional lead shielding needed to be added to the RTR Mobile trailer in some key spots. However, the real proof of the design and operational safety are the radiation surveys performed by a qualified expert under maximum voltage and current conditions, and, with and without a scattering configuration.

D.1.2 Initial Calculation Process, Methods, and Configurations

The process used to develop the X-ray shielding design assessment is as follows:

- Describe the physical layout of the trailer:
  - Figure 1 - Plan view layout
  - Figure 2 - Elevation view layout
- Describe the physical layout of "as-built" X-ray shielding
  - Figure 3 - Plan view of shielding
  - Figure 4 - Elevation view of shielding
- Attached Excel Spreadsheet - Tab: "VJT Shield Layout"
- Convert the steel thickness in floor, ceiling, and walls to a lead (Pb) equivalent for a 450 kV X-ray source.

See Reference "Radiation in Modern Industry Fourth Edition, Eastman Kodak Company, Rochester, New York 14650, Copyright 1980, Table IV, Approximate Radiographic Equivalence Factors." For X-rays, the equivalence factors between steel and lead is 12 at 220 kV, and 5 at 1,000 kV. Since the X-ray system being used in this application is 450 kV maximum potential, an equivalence factor of 8, which lies between the documented equivalence factors, was selected. In an analysis with any value from 5 to 12, the contribution by steel is very minimal.

- Describe the "worst case" rays to impact the shielding walls and where shielding thickness changes for the primary, leakage, and scattered beams.
  - Figure 5 - Plan view of ray layout
  - Figure 6 - Elevation view of ray layout
- Excel Spreadsheet - Tab: "Ray Layout," first three columns for ray description and distances
- Un-published empirical graphs/charts were used to estimate the required shielding thickness at various distances:

Attachment 2 – Shielding Calculations (Continued)

- See empirical charts attached for primary, leakage, and scattered radiation at limiting values of 0.25 mrem/hour and 0.75 mrem/hour.
- Excel Spreadsheet - Tab: “Empirical Charts Conversions,” reflects specific values from the empirical charts assembled in spreadsheet format over the range of ray distances used for trailer shielding.
- Excel Spreadsheet - Tab: “Ray Layout,” columns 4 to 6, estimates lead thickness for various “worst case” rays from d) above.
- Excel Spreadsheet - Tab: “Ray Layout,” column 9, current lead thickness in VJT trailer at the various “worst case” rays location from b) above.
- Consider the advantage because the radiation passes through the shield at an oblique angle. For an angle of obliquity θ material of thickness t has the shielding thickness t/cos θ. The angle of obliquity is provided in Column 7, the correction factor in column 8, and the corrected thickness in column 10.
- Estimate any additional lead shielding thickness requirement beyond the existing design as determined from empirical charts at value 0.25 mrem/hr. The specified system exposure limit requirement is 0.5 mrem/hr at 2-inches from any accessible surface. The 0.5 mrem/hr thickness values however, are not shown on these commonly used tables, so the use of the 0.25 mremremhr table is a conservative model and estimate for the trailer X-ray shielding design basis.
- Excel Spreadsheet - Tab: “Ray Layout,” Column 11
- Shielding configuration assumptions used in the above calculations
- Excel Spreadsheet - Tab: “Ray Layout,” Column 12
- The actual design verification method for the mobile RTR system will be accomplished by independent testing using calibrated exposure measuring equipment. The basis for this verification or validation method are straight forward;
- The system will be re-tested for leakage after it is deployed to the Idaho National Environmental and Engineering Laboratory site. This is a site RGD deployment requirement.
- As a minimum an annual or a semi-annual surveys of the system must be performed to meet federal and state legal requirements.
- The X-ray shield's integrity must be demonstrated again to meet the 0.5 mrem/hour limit to verify that the permanent installed X-ray shielding panels survived the shipping process as an intact entity and the “re-installed” removable panels are properly installed.
- Check Calculations as per ANSI N43.3 Annex D

Attachment 2 – Shielding Calculations (Continued)

- Check Calculation - Primary Beam (Ray P1)
- Using Equation 5 of Annex D, calculate K, then convert to lead thickness using Philips Curves converted to ANSI N43.3 format.

Equation:

K = Pd(squared)/WUT

where P is desired exposure (R/hr), d is distance from X-ray tube to location in question, W is workload (mA-min/hr), U is the use factor and T is the occupancy factor.

P = 5*E-4 R/hr

d = 3.1 meters

W = 60 (minutes/hr) x 9.3 (actual mA peak) = 558

U and T = 1

Therefore K = 8.6 E-6

From the Philips Curve converted to ANSI N43.3, a thickness of about 43 mm is derived.

Actual lead shielding equivalent (see Ray Layout) = 32.9 mm

D.2 Error Analysis

D.2.1 Required Shielding

Uncertainties in dimensions used and in the interpretation of data from the Philips curves are assessed as being of the order of ± 10%. When applied to the calculated 43 mm, this gives a required shielding of between 38.7 mm and 47.3 mm.

D.2.2 Discussion of Additional Shielding Considerations

Uncertainties in actual lead thickness are assessed as being ± 5%. When applied to the 32.9 mm, this gives an actual range of 31.25 mm to 34.55 mm.

The shielding effect of the Image Intensifier is not included in any of the calculations, however, the materials in its construction will both absorb the radiation (phosphors) and will scatter the radiation (metal alloys). The combined effect of this is assessed as introducing a further 10% of shielding effectiveness. This is equivalent to 3.4 mm.

Attachment 2 – Shielding Calculations (Continued)

In addition, a copper filter is fitted in the primary beam. This will also attenuate the lower energy X-rays, but no credit is taken in the calculations.

The shielding thickness assumes all radiation is at 90 degrees to the wall, whereas a proportion of the radiation will pass through the shielding at a variety of angles. This will increase the effective shielding thickness. It is assessed that the incident angle could be up to 60 degrees giving an increased shielding effectiveness of 40% for some of the radiation. However, a 10% increased effectiveness is considered reasonable. This is equivalent to 3.4 mm.

Using these assessments of the additional contribution to shielding, the actual shielding is calculated as being in the range 31.25 mm to 41.35 mm.

- Check Calculation - Leakage Radiation (Ray L1 and L2)

Rays L1 and L2 travel horizontally from the rear of the tube. Using the Pantak Leakage Radiation Diagram, the radiation emitted horizontally from the rear of the tube (for a 420kV source) is taken from the table of readings described as “180 – view A.” This is 140 mrem/hour at 1 meter. Although radiation in excess of this is emitted, the direction of this radiation is upwards and towards the center of the vault, not in the direction of Rays L1 and L2. (The orientation of the cable connectors on the installed tube has changed from the diagram, which shows the cable connectors pointing downwards at a “5 o’clock” position, to the cable connectors pointing upwards at an “11 o’clock” position.)

At 50 mm outside the shielding (a total of 0.66 meters from the source) the radiation equals 321 mrem/hour for a 420 kV source. By extrapolating the Pantak data for the 320 kV source through to the 420 kV source, it is estimated that the radiation from the 450 kV source is about 1.7 to 2.6 times higher. This gives a worst case of 835 mrem/hour.

- The TVL for lead at 450 kV equals 10 mm, and HVL equals 3 mm (from Table B1, ANSI N43.3)
- The shielding is assessed as 32.3 mm lead ± 5%. Range of shielding equals 30.6 mm to 33.9 mm.
- Attenuation using TVL is 8.71E-4 for 30.6 mm lead, and 4.07E-4 for 33.9 mm lead.
- Attenuation using HVL is 8.50E-4 for 30.6 mm lead, and 3.97E-4 for 33.9 mm lead.
- Average of the two gives 8.61E-4 for 30.6 mm lead, and 4.02E-4 for 33.9 mm lead.

Attachment 2 – Shielding Calculations (Continued)

- Calculated radiation at L1 is therefore in the range 0.73 mrem/hour to 0.34 mrem/hour.

D.3 Check Calculation - Scatter Radiation (Examples - Rays S2 And S8)

Ray S2 and Ray S8 were chosen as they represent scatter radiation paths, which are directed towards areas potentially occupied by people, either routinely or intermittently.

D.4 Ray S2 (Exits The Trailer Side To An Area Where People Could Pass Through)

Using Equation 7 of Annex D, calculate K, then convert to lead thickness using Philips Curves converted to ANSI N43.3 format.
Attachment 2 – Shielding Calculations (Continued)
Attachment 2 – Shielding Calculations (Continued)

<u>Equation:</u>

K = 400Pd(sec)(squared)d(sca)(squared)/aWTF

where P is desired exposure (mrem/hr), d(sca) is distance from X-ray tube to scattering object, d(sec) is distance from scattering object to location in question, a is ratio of scattered to incident radiation, W is workload (mA-min/hr), T is the occupancy factor, and F is the area in square centimeters of the radiation field at the scattering object.

P = 5*E-4 R/hr

d(sec) = 2.55 meters
d(sca) = 1.35 meters

W = 60 (minutes/hr) x 9.3 (actual mA peak) = 558

T = 1

a = 0.0015 (scatter angle of 90 degrees for steel, from Table D2 ANSI N43.3. Note: there is no data available for 450kV. The 300kV data was used, although the scatter angle is significantly less than 90 degrees, but the only data available is for a 90 degree scatter angle.)

F = area of primary beam impinging on the surface of a drum, nearest to the X-ray tube. Nominal 12 degree beam angle at 1.35 meters has radius of about 14 cm, plus the effect of the elongated collimator, therefore F = 920 is used.

The calculated value for K of 3.08E-3 requires a thickness of about 19 mm using the Primary Radiation Curve of the Philips Curve converted to ANSI N43.3 format.

Attachment 2 – Shielding Calculations (Continued)

The actual lead shielding is 7.3 mm ± 5%, however, as this radiation is incident on the shielding at an angle of approximately 30 degrees the effective shielding thickness is in the range of 8 mm to 8.8 mm.

D.5 Ray S8 (Exits The vault Into The Direction Of The Control Room)

The above calculation for ray S8 is:

P = 5*E-4 R/hr

d(sec) = 3.1 meters
d(sca) = 1.35 meters

W = 60 (minutes/hr) x 9.3 (actual mA peak) = 558

T = 1

a = 0.0015 (90 degree scatter angle, steel)

F = 920, although the actual effective area could be significantly less.

The calculated value for K of 4.55E-3 requires a thickness of about 18 mm using the Primary Radiation Curve of the Philips Curve converted to ANSI N43.3 format.

The actual lead shielding is 10.5 mm ± 5%. With the majority of this ray impinging normal to the wall, the effective lead thickness is considered to be in the range 10 mm to 11 mm.

Attachment 3 – Drawings

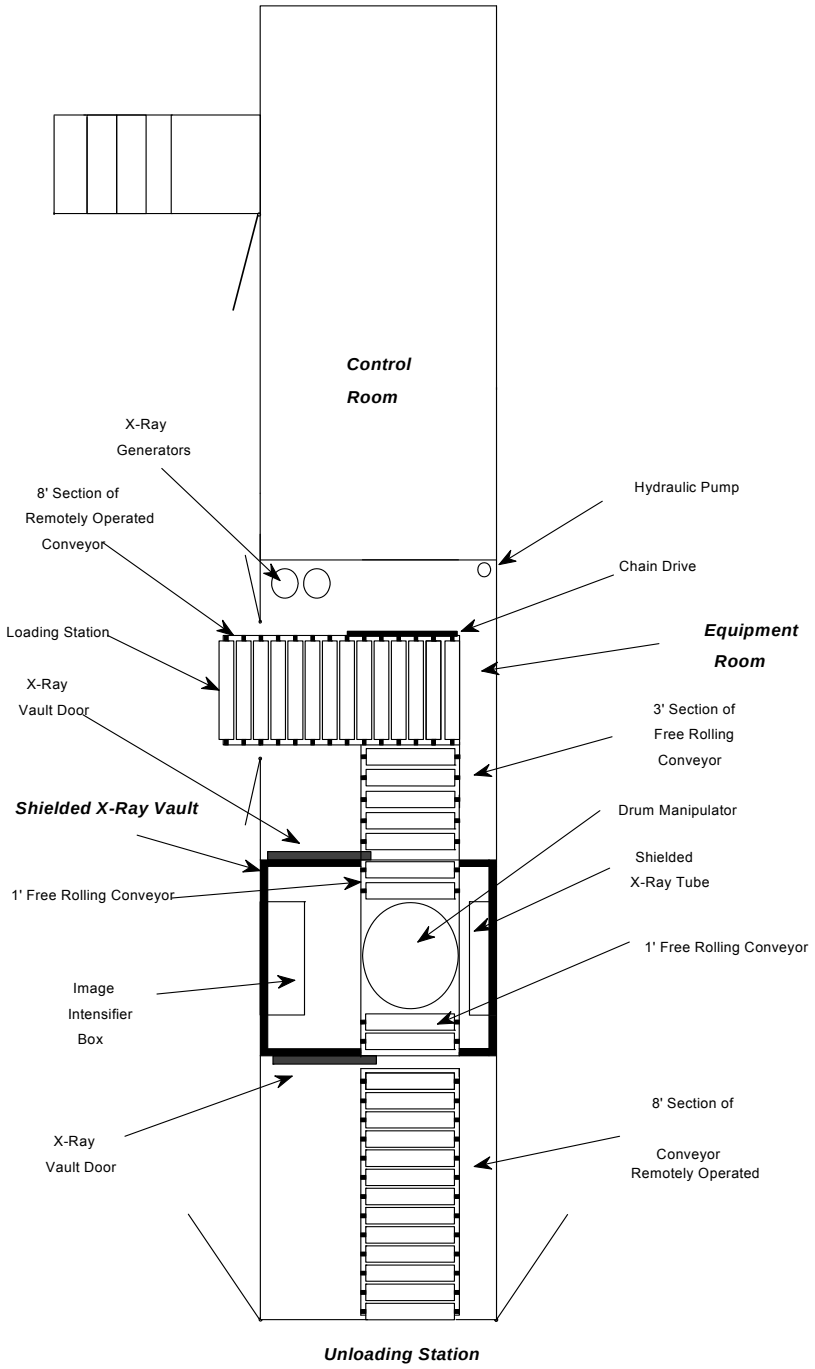

Figure 1. Layout

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Attachment 3 – Drawings (Continued)

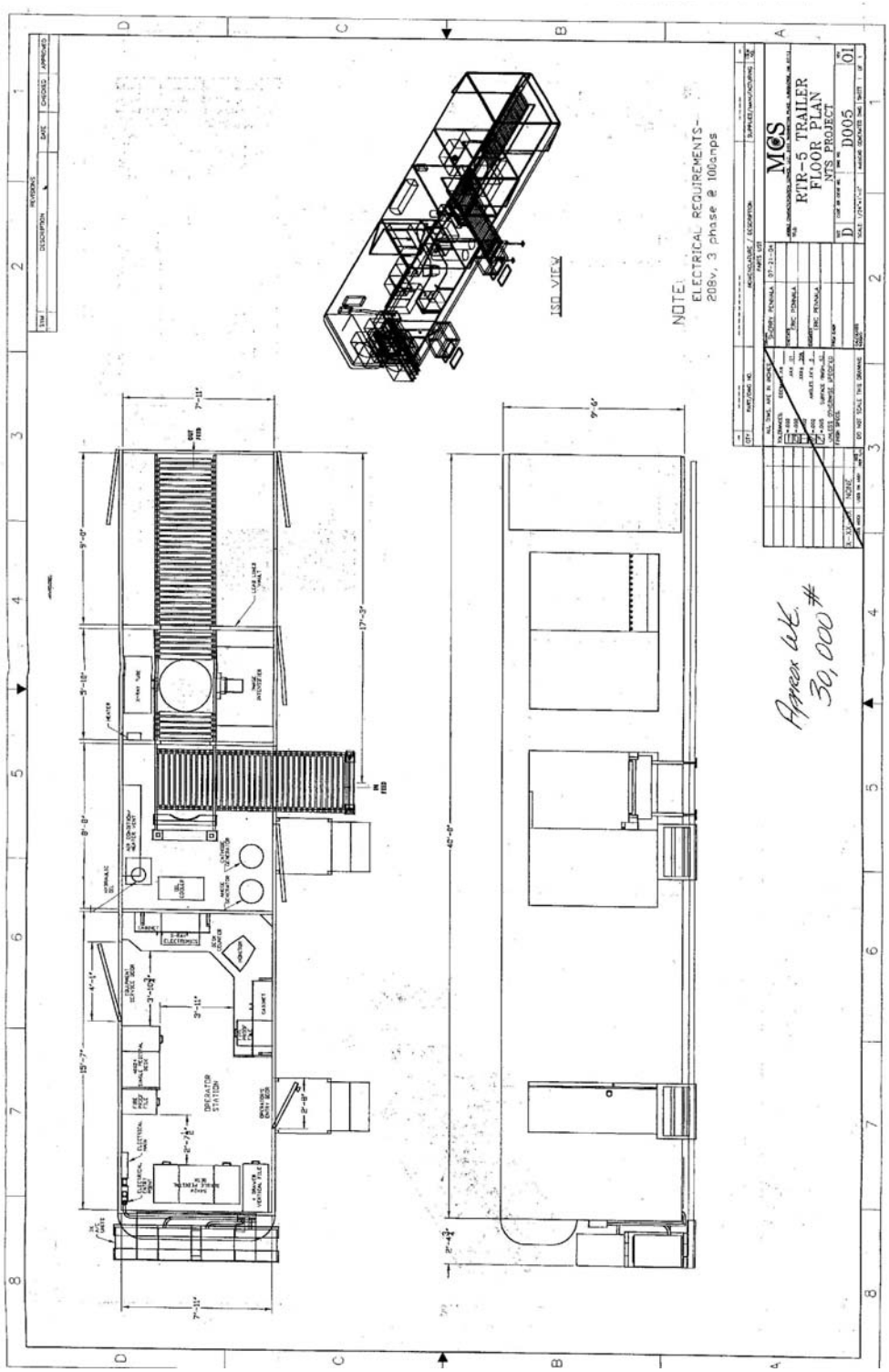

Figure 2. Interior Elevation View of RTR-5

Attachment 4 – Photographs

1. Photographs 1 through 25 are from an equipment walk-down performed May 17, 2006 at the Idaho National Laboratory (INL) facility in Idaho Falls, Idaho

2. Photographs 1, 1a, 3, and 4, position from the rear loading area: Note, 1) warning signs, 2) interlock on vault door, 3) camera, 4) fire extinguisher, 5) unload conveyor

3. Photograph 2 is positioned from outside roadside of trailer: Note, 1) load conveyor less than 4-feet off surface

4. Photographs 5 and 6, position from loading area (roadside): Note, 1) Load conveyor, 2) Hydraulic lines

5. Photograph 7, position from load side of vault: Note, 1) interlock and limit switches

6. Photographs 8, 9, 10, and 11, position inside vault: Note, 1) X-ray generators, 2) hydraulic pump and motor, 3) hydraulic pump and pump bar, 4) push bar

7. Photographs 12 and 13, position from load side: Note, 1) conveyor, 2) floor

8. Photograph 14, position from inside Equipment Bay: Note, 1) camera, 2) walls, 3) electrical control panel with emergency stop

9. Photographs 15 and 16, position outside trailer: Note, 1) HVAC for climate control in control room, 2) structural frame the trailer is sitting on

10. Photographs 17 and 18, position from outside trailer (front and side views): Note, 1) electrical connections
11. Photographs 19 through 26, position from inside control room: Note, 1) control room equipment, 2) door with turn handle, 3) visual monitors, 4) fire extinguisher & alarm, 5) E-stop on panels, 6) cameras, 7) HVAC unit

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Attachment 4 – Photographs (Continued)

Photograph 1

Attachment 4 – Photographs (Continued)

Photograph 1a

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Attachment 4 – Photographs (Continued)

Photograph 2

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Attachment 4 – Photographs (Continued)

Photograph 3

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Attachment 4 – Photographs (Continued)

Photograph 4

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Attachment 4 – Photographs (Continued)

Photograph 5

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Attachment 4 – Photographs (Continued)

Photograph 6

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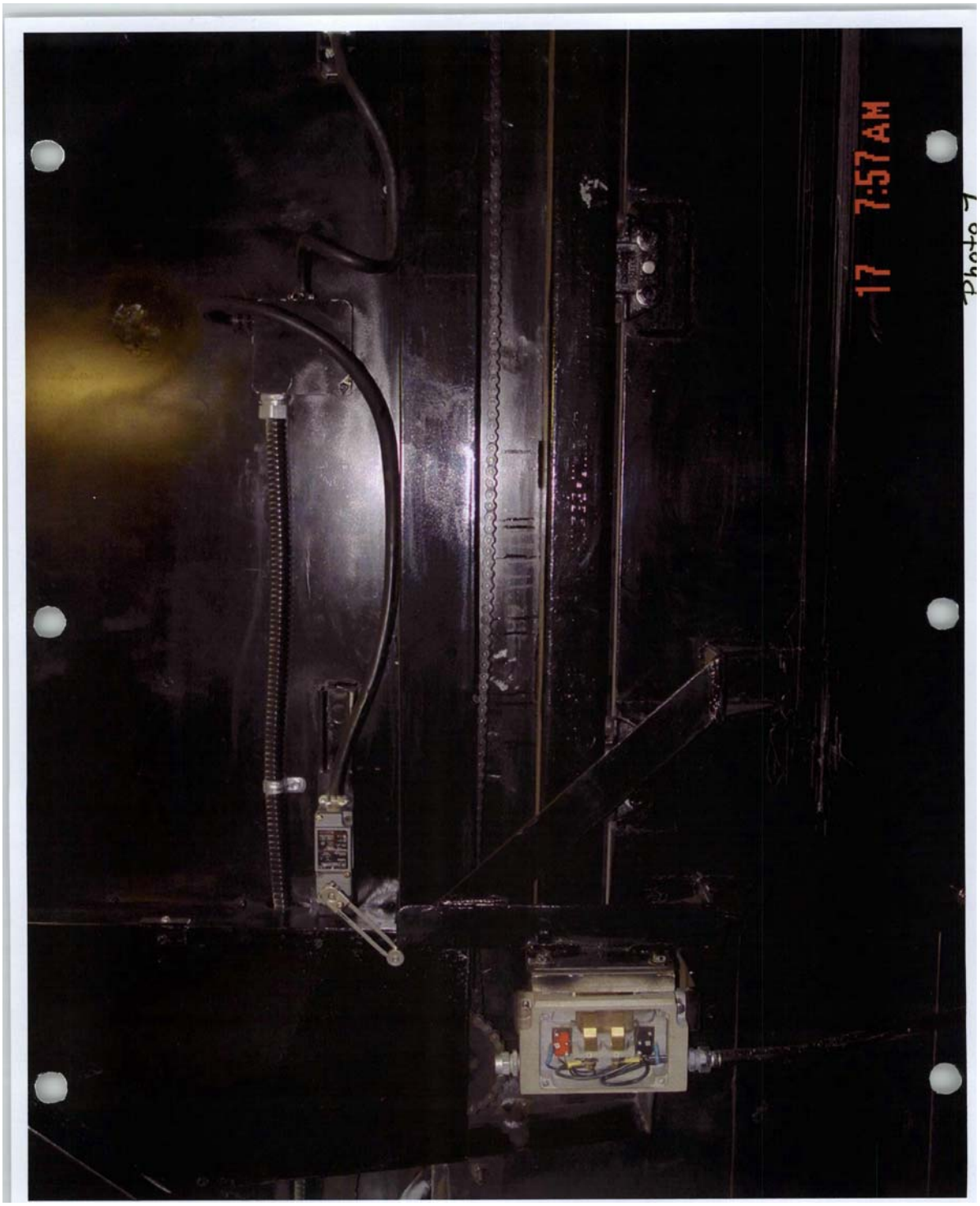
Attachment 4 – Photographs (Continued)



Photograph 7

Attachment 4 – Photographs (Continued)

Photograph 8

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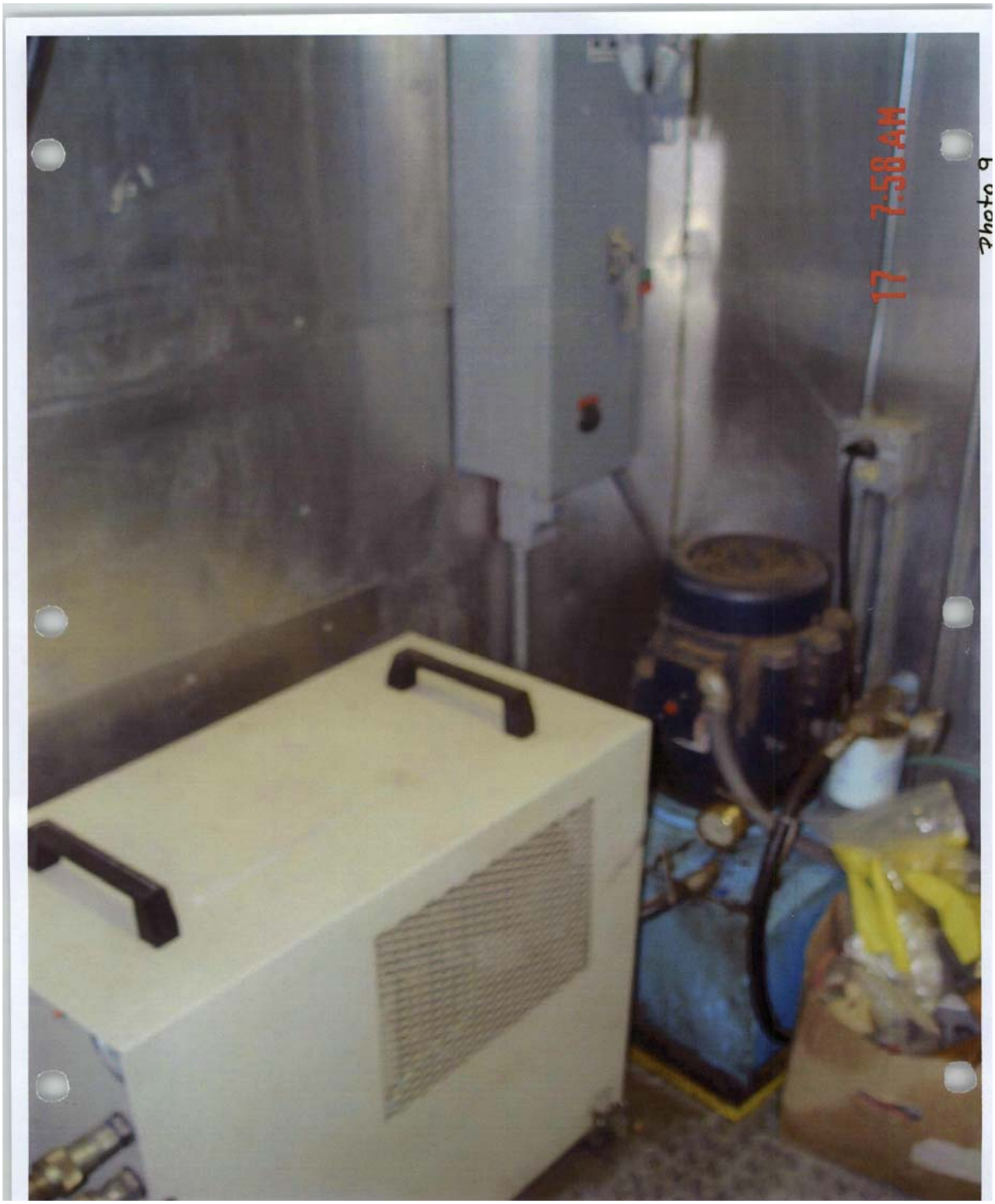
Attachment 4 – Photographs (Continued)



Photograph 9

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Attachment 4 – Photographs (Continued)

Photograph 10

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Attachment 4 – Photographs (Continued)

Photograph 11

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Attachment 4 – Photographs (Continued)

Photograph 12

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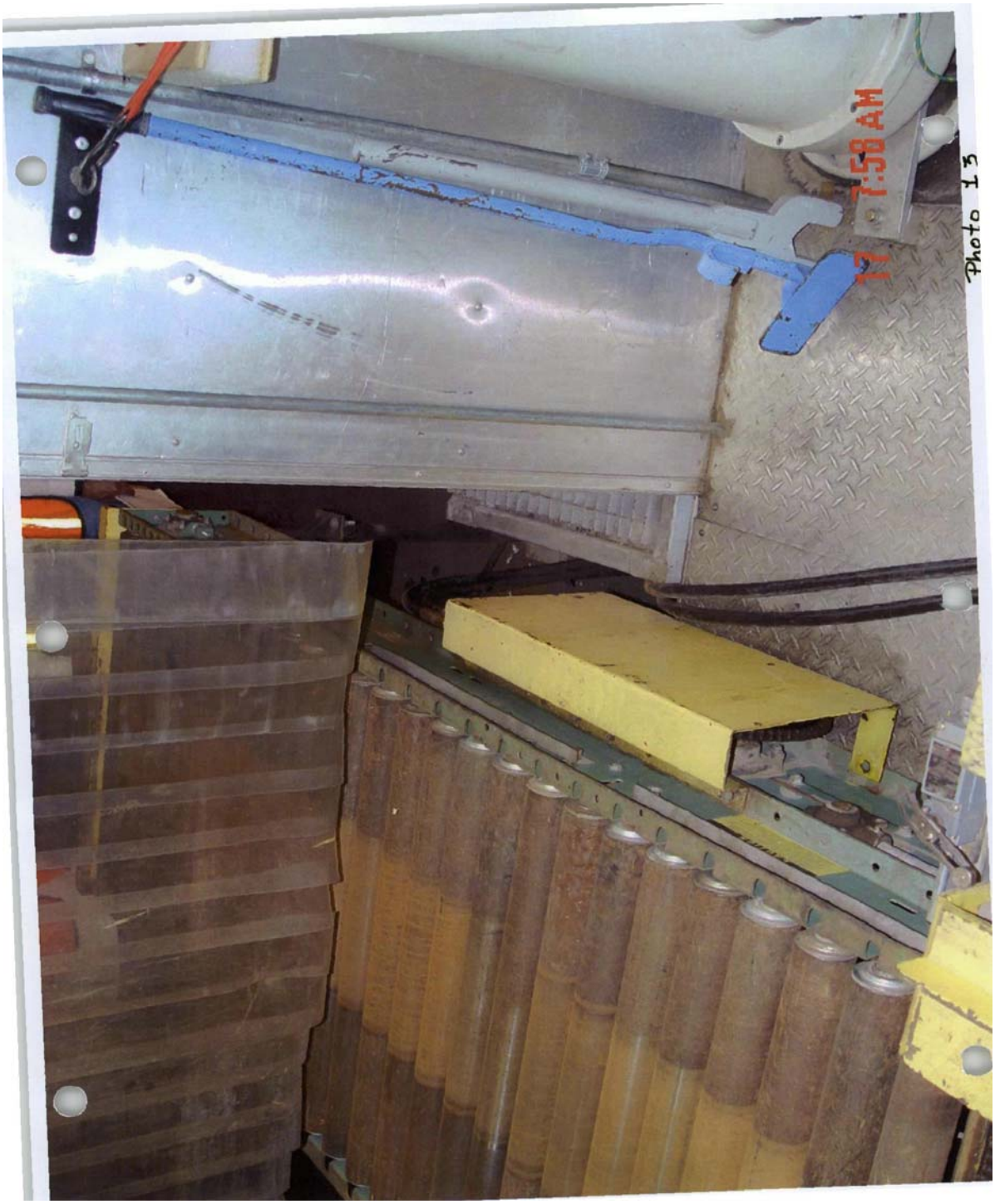
Attachment 4 – Photographs (Continued)



Photograph 13

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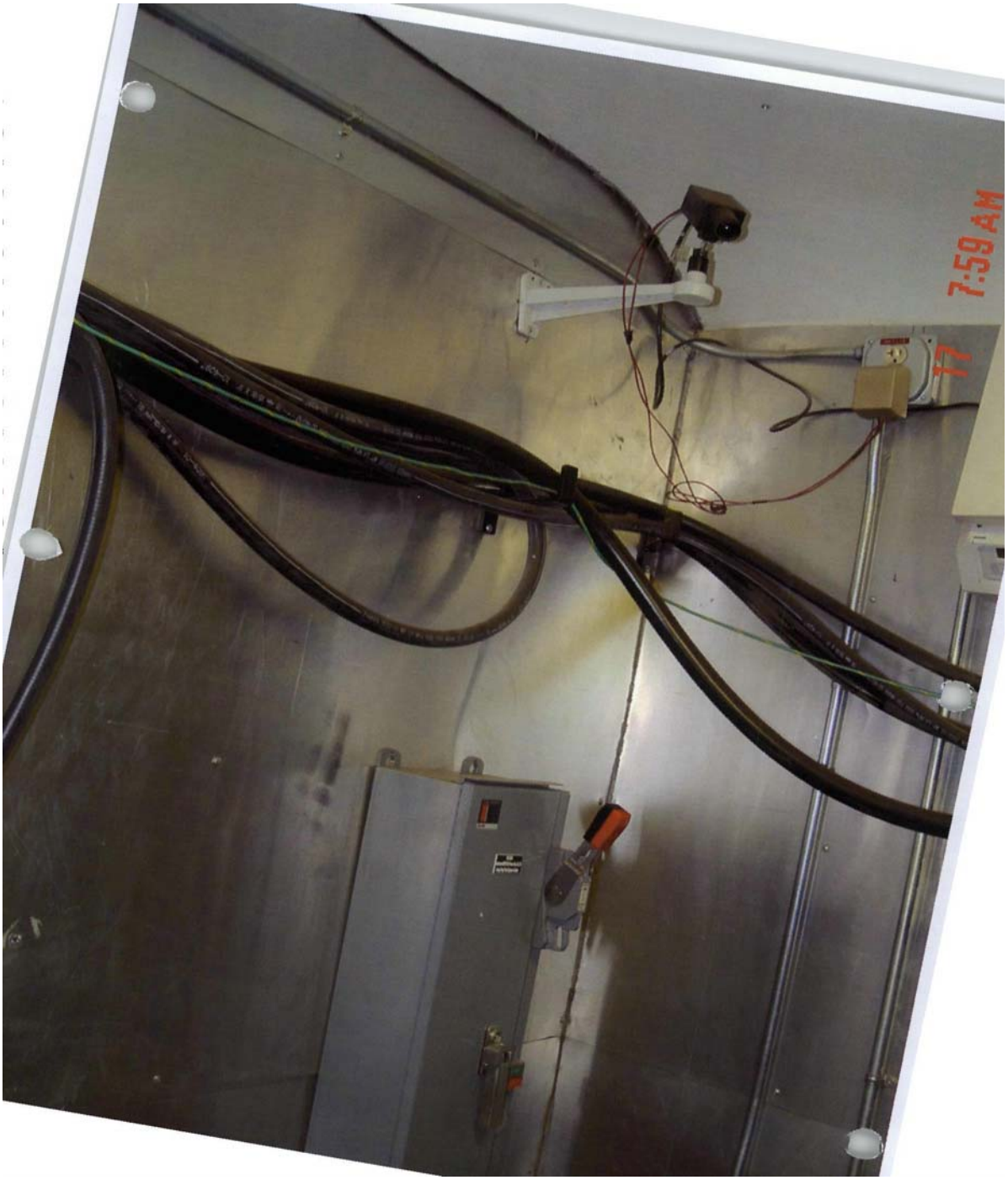
Attachment 4 – Photographs (Continued)



Photograph 14

Attachment 4 – Photographs (Continued)

Photograph 15

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Attachment 4 – Photographs (Continued)

Photograph 16

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Attachment 4 – Photographs (Continued)

Photograph 17

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Attachment 4 – Photographs (Continued)

Photograph 18

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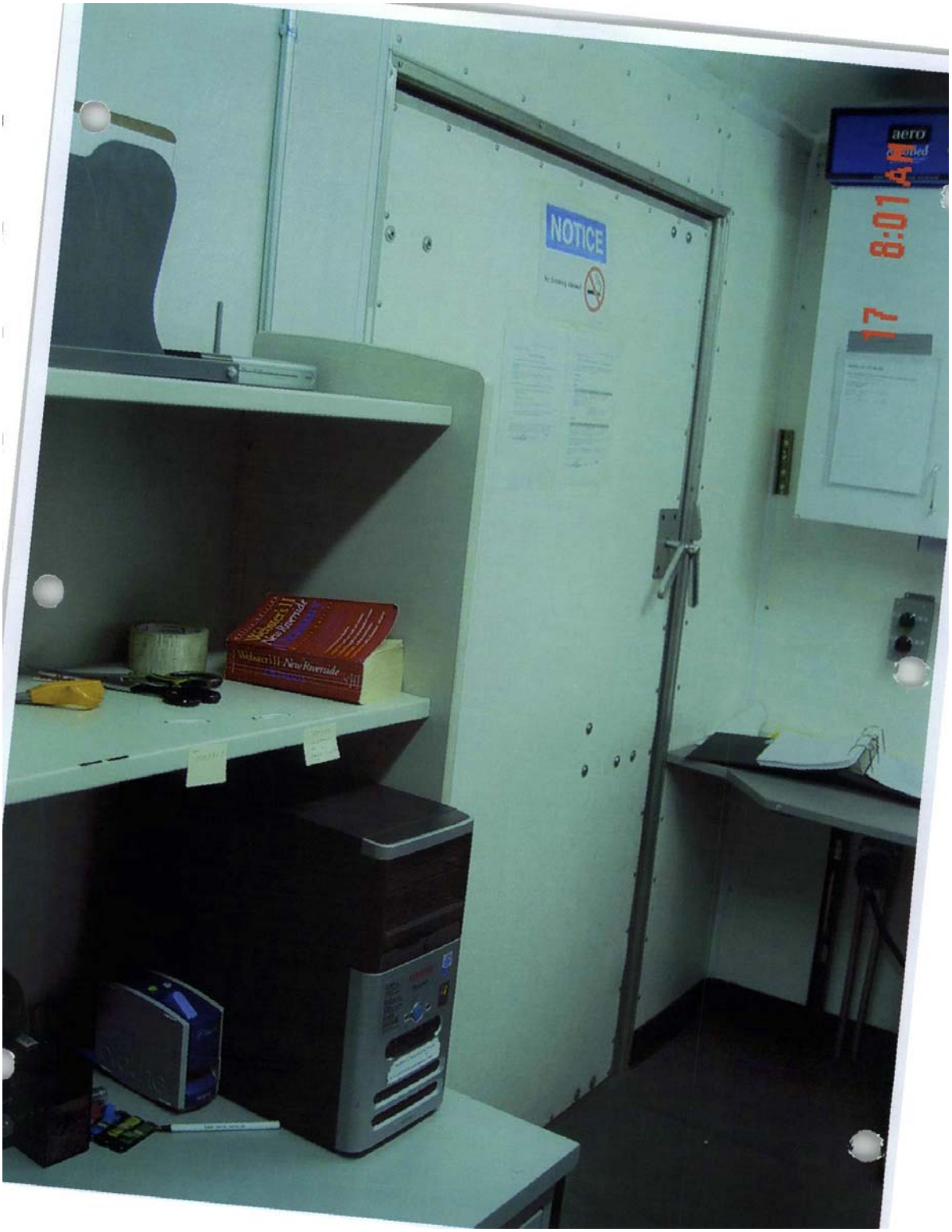
Attachment 4 – Photographs (Continued)



Photograph 19

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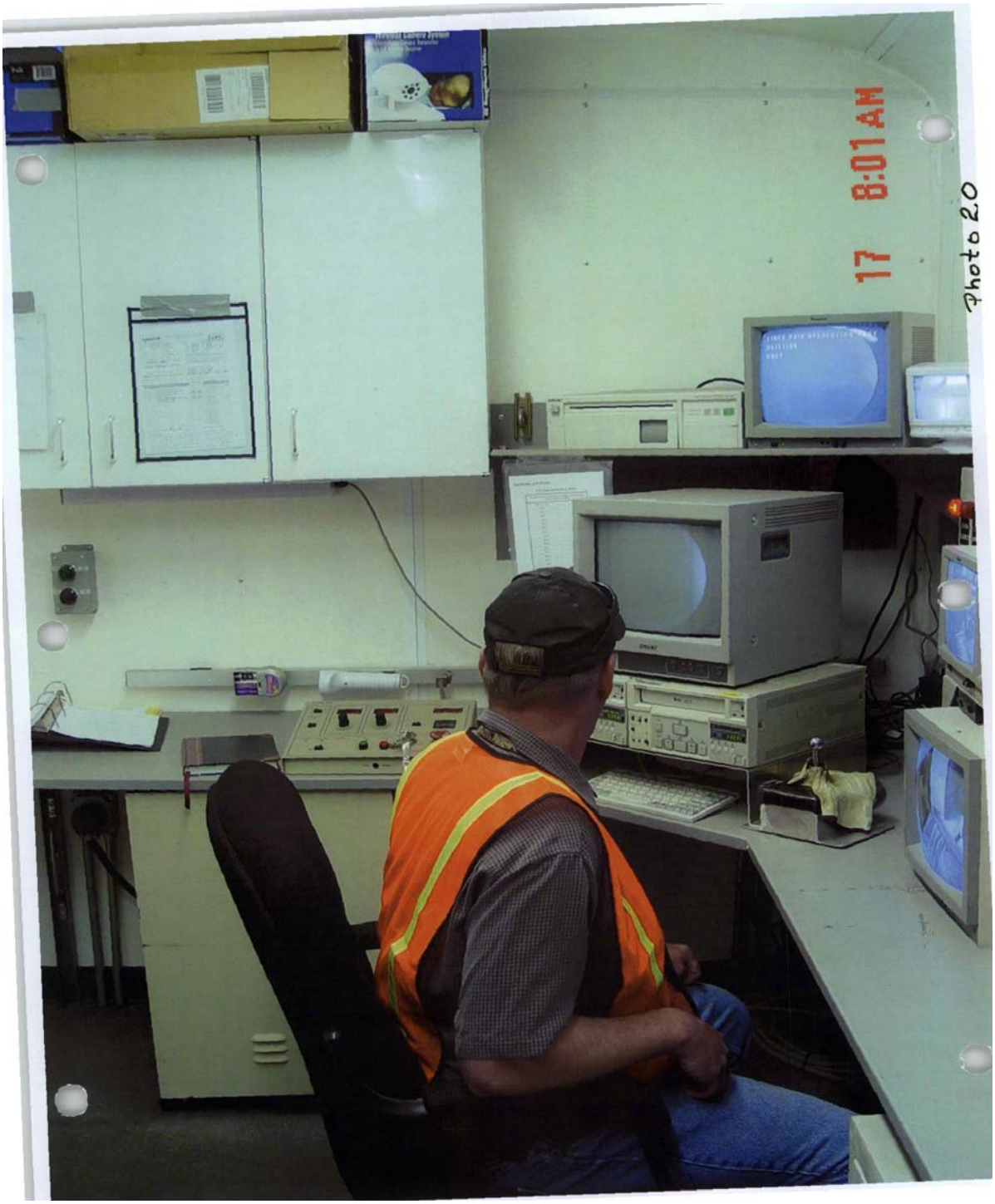
Attachment 4 – Photographs (Continued)



Photograph 20

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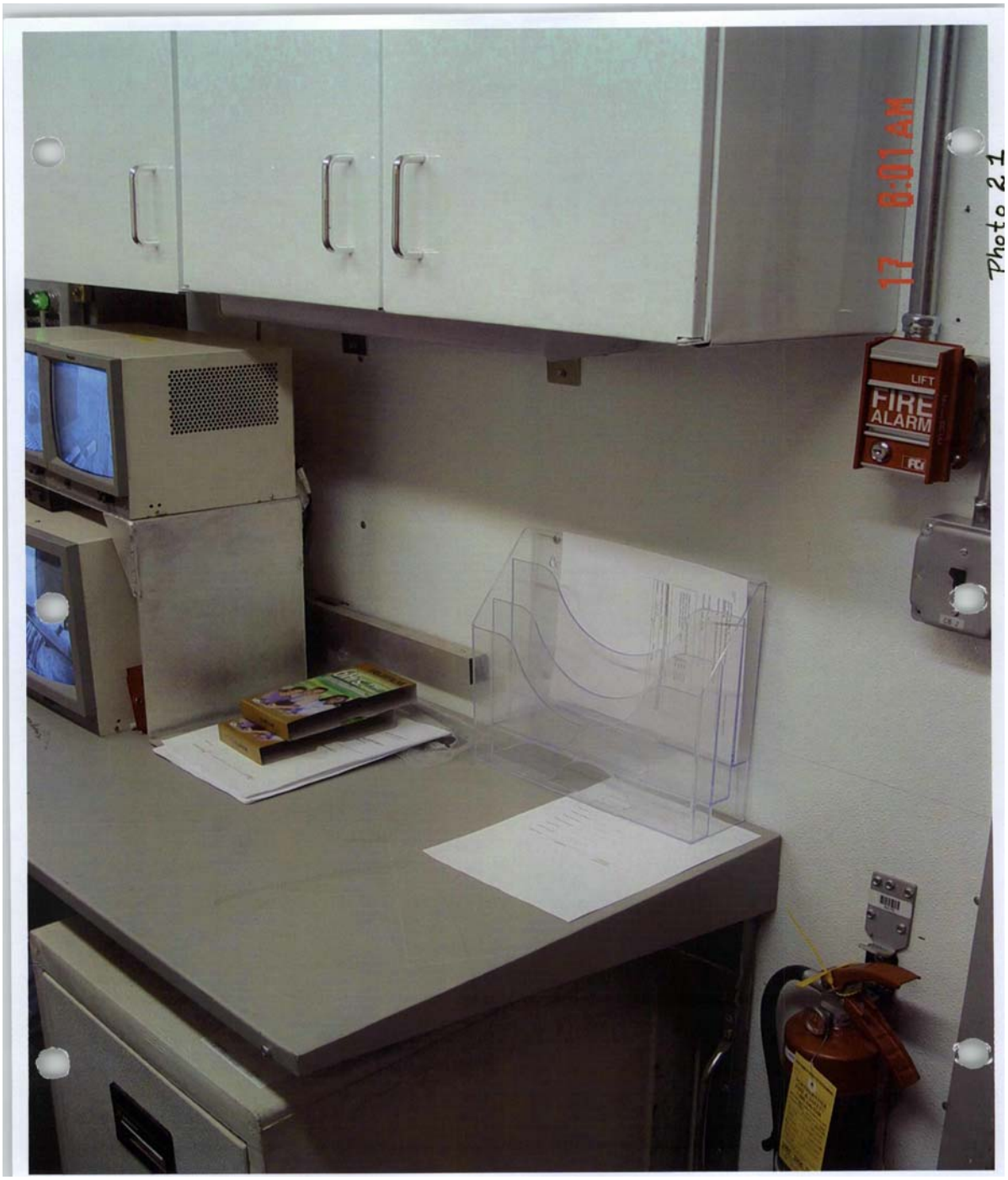
Attachment 4 – Photographs (Continued)



Photograph 21

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Attachment 4 – Photographs (Continued)

Photograph 22

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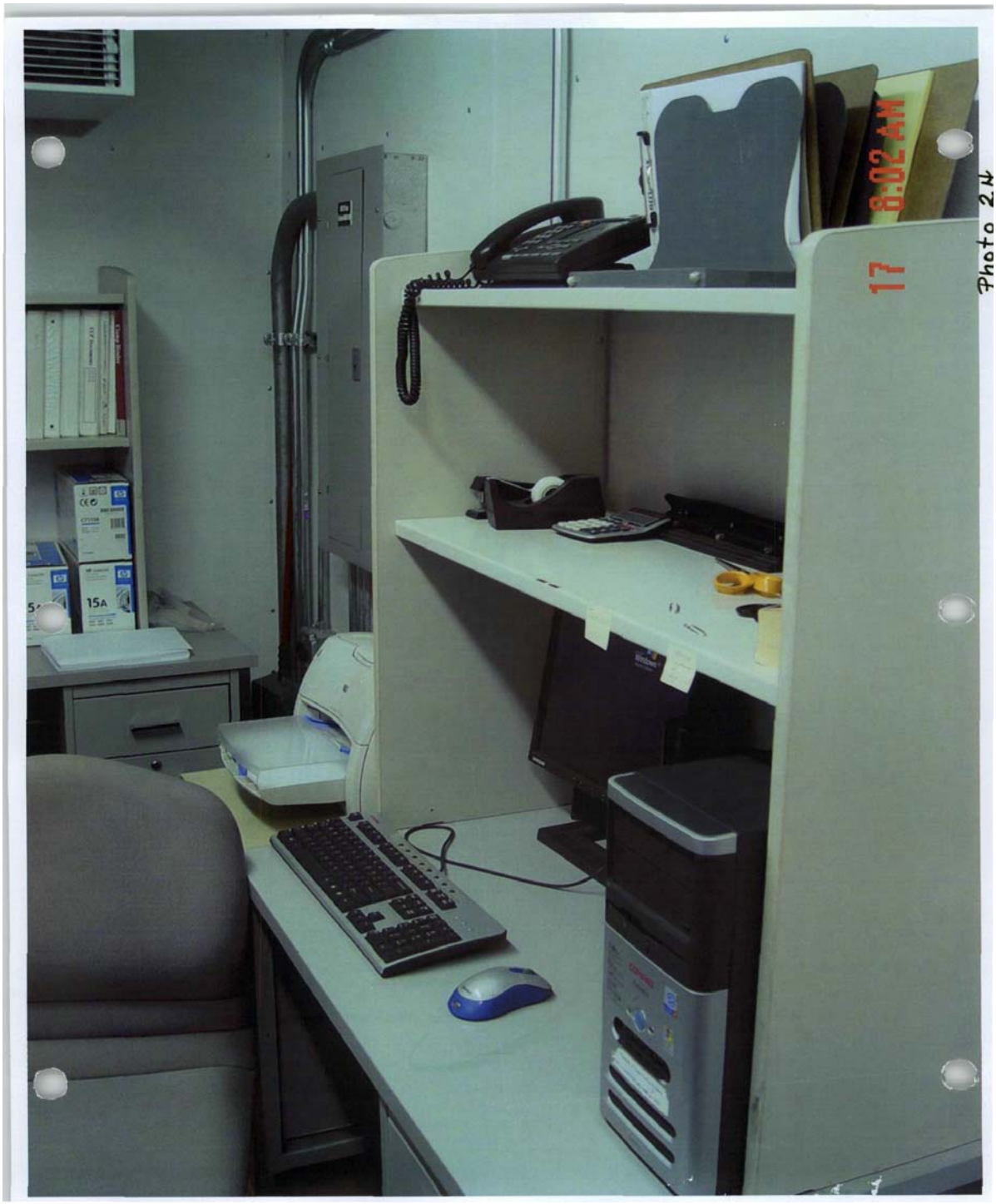
Attachment 4 – Photographs (Continued)

Photograph 23

Attachment 4 – Photographs (Continued)



Photograph 24

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Attachment 4 – Photographs (Continued)

Photograph 25

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Attachment 4 – Photographs (Continued)

Photograph 26