UNIVERSITY OF MISSOURI PICKARD HALL DECOMMISSIONING RADIOLOGICAL WORK PLAN

Pickard Hall
405 S. Ninth Street
Columbia, MO 65211-1420

US Nuclear Regulatory Commission
Radioactive Material License 24-00513-32

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Revision 0

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ACRONYMS

ACM	Asbestos-Containing Material
ALARA	As Low As Reasonably Achievable
BGS	Below Ground Surface
CFR	Code of Federal Regulations
COC	Chain of Custody
CRSO	Chase Radiation Safety Officer
DAC	Derived Air Concentration
DAW	Dry Active Waste
DCGL	Derived Concentration Guideline Level
DOT	US Department of Transportation
DP	Decommissioning Plan
DQA	Data Quality Assessment
DQO	Data Quality Objective
EF	Emanation Factor
EHS	Environmental Health and Safety
ES&S	Engineering Surveys & Services
FSS	Final Status Survey
GPS	Global Positioning System
HEPA	High Efficiency Particulate Air
HSA	Historical Site Assessment
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
MU	University of Missouri
MU CF-PDC	MU Campus Facilities Planning, Design, and Construction
MURSO	University of Missouri Radiation Safety Officer

NRC	U.S. Nuclear Regulatory Commission
NIST	National Institute of Standards and Technology
NORM	Naturally Occurring Radioactive Materials
PHDP	Pickard Hall Decommissioning Project
PM	Project Manager
PPE	Personal Protective Equipment
QA	Quality Assurance
RCS	Radiation Control Supervisor
RCT	Radiation Control Technician
RM	Radwaste Manager
RPP	Radiation Protection Program
RSM	Radiation Safety Manual
RW	Radiation Worker
RWP	Radiation Work Permit
SWPPP	Stormwater Pollution Prevention Plan
TEDE	Total Effective Dose Equivalent
THH	Trabue, Hansen, & Hinshaw, Inc.
TLD	Thermoluminescent Dosimeter
USDA	US Department of Agriculture
WCS	Waste Control Specialists

1.0 EXECUTIVE SUMMARY

The University of Missouri (MU) identified residual radioactivity from historical operations conducted in Pickard Hall located at 405 S. Ninth Street, Columbia, MO 65211-1420. Built in 1892 as the Chemistry Building, Pickard Hall was subsequently used as the Museum of Art and Archaeology and housed the Department of Art History and Archaeology. Building occupants were moved out from 2013 to 2014 and removal of museum pieces was completed in 2017. The building has a footprint of 8,400 square feet with approximately 24,600 gross square feet of floor area over three elevations (not including an attic). The building is located within the Francis Quadrangle, which is listed on the National Register of Historic Places. See Appendix A for a satellite photo.

In the early 1900's, the basement of Pickard Hall was used for separation of radium-226 from uranium ores and research with thorium-232 daughters (specifically Ra-228 as a potential substitute for Ra-226). Additionally, the purified materials may have been used in other areas of the building. These radioactive materials had historically been regulated by the State of Missouri but became licensed by the US Nuclear Regulatory Commission (NRC) in 2009 under the broad scope license 24-00513-32 due to implementation of the NRC's expanded definition of byproduct material in 2007.

As a result of these historical operations, Pickard Hall contains residual radioactivity on some building structures, and in isolated areas of soil around and under the building. The total residual radioactivity on building structures is estimated to be 796 μCi. Demolition of the building would not release this material into the environment at concentrations that would pose a risk to public health.

The Pickard Hall Decommissioning Project (PHDP) will be conducted in three phases:

- Phase 1: Demolition
- Phase 2: Characterization
- Phase 3: Remediation and Final Status Surveys

This phased approach recognizes that demolishing the building and removing its concrete slab foundation (*i.e.*, Phase 1) can proceed without additional characterization of subsurface soil (*i.e.*, Phase 2). MU will perform additional soil analysis after the building and its concrete slab are removed.

MU retained the Chase Environmental Group Inc. (Chase) to assist MU in the development and implementation of the Decommissioning Plan (DP) for the PHDP. The goal of the PHDP is to demolish the building and then accomplish unrestricted release of remaining soils and structures such as abutting steam and utility tunnels. As such, a quantitative ALARA analysis is not required to be included in this DP.

The DP is comprised of four separate plans:

- This Radiological Work Plan – provides the historical site assessment (HSA), radiological information, and project management organization applicable to all phases of the PHDP.
- Demolition Plan - describes the plan for building demolition and disposal of clean and contaminated demolition materials.
- Characterization Plan - describes radiological characterization activities to be conducted after building demolition on soils and remaining structures, such as the abutting steam tunnels. After demolition of the building and its foundation, MU will take samples of the near-surface soils (that is, the top two feet) to characterize the extent and amount of any radiological contamination. This approach will allow characterization work to proceed as soon as demolition is complete to avoid potential security and safety issues created by having a demolition pit on an active university campus. The soil characterization data will be used to update the Remediation and Final Status Survey Plan if necessary.
- Remediation and Final Status Survey Plan - describes plans for remediating soils and structures, as needed, after building demolition as well as the plans for final status surveys to achieve unrestricted release of the site.

The DP (consisting of the four plans described above) was developed using the guidance provided in NUREG-1757, “Consolidated NMSS Decommissioning Guidance,” NUREG-1575, “Multi-Agency Radiation Survey and Site Investigation Manual” (MARSSIM), and interactions with the NRC Staff during its reviews of prior submittals regarding the planned decommissioning of Pickard Hall. The DP provides the approach, methods, and techniques for radiological decommissioning of impacted areas of the site. Chase’s decommissioning activities will be conducted under its Commonwealth of Kentucky Radioactive Materials License 201-605-15 utilizing a reciprocal agreement with the NRC. At all times, including periods when no active decommissioning work is being performed, the site will be maintained under the MU Broad Scope radioactive materials license which permits MU’s possession of Ra-226, natural uranium, and natural thorium “for possession only, incident to decommissioning activities.”

This Radiological Work Plan includes information common to all three phases of the PHDP, such as the historical site assessment, radiological information, and project management organization. Each project phase has supporting documentation specific to that phase and which references the information in this Plan.

MU has chosen a very conservative path for decommissioning intended to remove all building debris (whether radioactive or not) and contaminated soil, and to transport that debris and soil off-site for disposal. Building debris will be disposed as radioactive waste or as clean demolition debris as appropriate; demolition rubble will not be recycled. After removal of demolition debris and remediation of contaminated soils, remaining soils and adjoining structures such as the steam tunnel will be surveyed to demonstrate compliance with site-specific Derived Concentration Guideline Levels (DCGLs) calculated using RESRAD version 7.2 for soils and RESRAD-BUILD version 4.0 for structures.

MU requests a license amendment to incorporate this DP in broad scope license 24-00513-32. MU anticipates that all decommissioning activities will be completed within 24 months of initiation.

2.0 FACILITY OPERATING HISTORY

MU and Chase conducted an HSA to determine the operational history of the building relative to decommissioning. Originally called the Chemistry Building, over the years Pickard Hall has been referred to as the Chemical Laboratory, Old Chemistry Building, School of Commerce, and the Art History and Archaeology Building. The name was eventually changed to Pickard Hall, to honor Professor John Pickard, the first chair of the Department of Art History and Archaeology.

2.1 History of the Chemistry Department

Upon completion of construction in 1892, the building housed the Chemistry Department. As the Chemistry Department grew to include organic, agricultural, general, analytical, technical, industrial, and physical chemistry began to outgrow the facilities, professors met in 1911 to examine their relocation options. It was decided that general laboratories and other offices would share the top floor of the new Schweitzer Hall, originally constructed for agricultural chemistry. A third home for the Chemistry Department, Schlundt Hall, was completed in 1923, but it was still not large enough to house the entire department. By 1951, general, analytical, technical, industrial, and physical chemistry had moved to other buildings, leaving only organic chemistry in the old building (Pickard Hall). By 1969, plans were approved for a new chemistry building that opened in November of 1972, consolidating the Chemistry Department to one building for the first time since 1912. Subsequently, Pickard Hall housed the Art and Archaeology Museum from 1976 until 2013. Currently, the building is unoccupied with all museum artifacts removed.

2.2 History of Radium Processing

Professor Herman Schlundt had the greatest impact on the current contamination of Pickard Hall. Schlundt began his career at MU in 1901. By 1911, he became the chairman of the chemistry faculty. In 1913, he was introduced to radium refining when he spent time at the U.S. Bureau of Mines in Denver, Colorado. There he learned the method of converting ore into "tiny crystals of radium bromide salts" (Columbia Missourian, July 16, 2013). The process was described as laborious, messy, and dangerous. From 1913 through the mid 1930s Schlundt focused his research on radium.

In 1914, Schlundt returned to the university but did not end his refining research. He partnered with fellow researcher, Howard H. Barker and the two found new ways to make the refining process more efficient and cost effective.

2.2.1 Economic Factors Driving Radium Production

The scarcity of radium contributed to its value, which at the time was higher than gold or diamonds. In fact, "according to the New International Yearbook: A Compendium of the World's Progress, published in 1921, radium sold for $115 to $120 per milligram that year, gold cost about $21 per troy ounce—roughly 1.09 ounces—that year, according to the National Mining Association. A milligram of gold would have been worth just 0.0007 dollars" (Gibbons, 2013).

2.2.2 Business Arrangements with Commercial Entities

In addition to his responsibilities to the university, Schlundt was contracted as a consultant for the Welsbach Company due to his well-known refining expertise. The company made mantels for gas lanterns and utilized a method of extracting thorium that produced a large amount of radioactive waste. They needed Schlundt to turn the waste into a source of new profit by extracting radium-228. A letter from Schlundt claims that his graduate students had refined more than 3,600 milligrams of radium-228 in a 12 -year period. "These 3,600 milligrams had a market price of between $216,000 and $360,000 at the time, according to prices Schlundt quoted in his letters" (Gibbons, 2013).

2.2.3 Radium Production Processes

Schlundt appealed to individuals and companies to donate ores containing radium, ultimately receiving over 4 tons. The concentration of radium within the ore was such that the refining techniques only yielded a couple hundred milligrams per ton of raw ore. The small amount of radium produced per ton of ore also meant there was a large amount of waste, a vast majority of which was returned to the donors.

Radium is extracted from uranium ore by crushing it and then dissolving it in sulfuric acid. The resulting precipitate contains radium salts, barium salts, and other compounds. This precipitate is treated with chemicals to produce a solution of radium bromide. Radium is produced by crystallization and filtration of the radium bromide solution (Radium, 2009).

2.2.4 Description of Radium Processing Equipment/Operation

A laboratory was established in the basement to test radium separation techniques. Commercial production was not an objective. Differing sources of carnotite ore were received. Ore was crushed and then digested in an acid. At about the time that the major part of the research was complete in the fall of 1922, radium prices drastically declined due to the discovery of very rich deposits of uranium ore in the Belgian Congo (15-20 times that of American deposits).

The separation equipment was installed in what is now rooms 12, 12A, 13, 13A, and 15. The layout of the equipment is presented in Figure 2-1.

Many compromises were made regarding equipment. Equipment designed for different functions or operational scale was adapted for use in the radium separation process. All of the equipment requiring power was driven from one line shaft powered by a five-horsepower motor. Preliminary preparation of ores includes grinding to pass 20 mesh before chemical treatment, the manner of which greatly affects the radium extraction efficacy. Grinding and crushing consisted of one small Braun jaw crusher and one Braun disc pulverizer. This equipment was serviceable, but not well suited for this scale of operation. The existing Chemistry Department air compressor was utilized to power a small vacuum pump and receiver tank. Utilities used in the operation included tap water, distilled water, natural gas, steam, air, and vacuum.

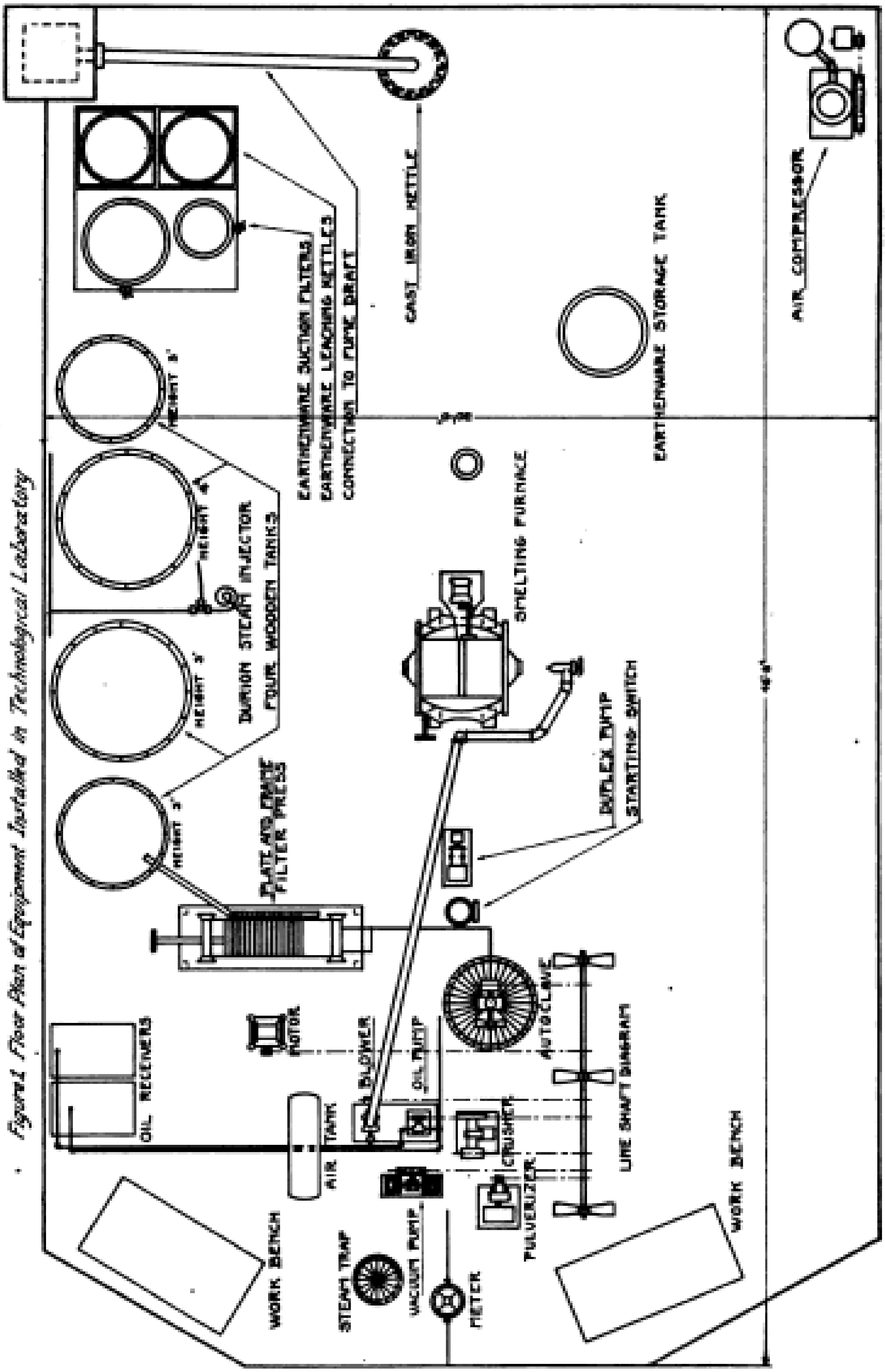

Figure 2-1: Radium Separation Equipment Layout

Acid Treatment Equipment

Two round-bottom stoneware leaching pots (24-gallon and 37-gallon) were used as boiling pots for treatment of ores with acid. Pots were housed in boxes mounted on an elevated platform and packed in hay to hold them in position. The pots were serviced by water, air, and steam. Charges of ore up to 100 pounds could be treated in the larger pot.

Acid solutions from the pots were filtered with two nearby stoneware suction filters at a lower elevation to accommodate direct siphoning into the filters. The larger filter had 45-gallon upper and lower chambers, and the smaller filter had an 11-gallon upper chamber and 22-gallon lower chamber. The filter media consisted of filter cloth and sand. Live steam was passed into the mixture of ore and acid, then cooled by running cold water.

The leaching pots and suction filter layout is depicted in Figure 2-2. The photo is taken looking northeast. The exhaust flue is apparent in the corner of the room. Note that the basement walls were bare brick at the time and were subsequently covered in plaster, likely during the 1940 renovation. Also, the floor appears to be concrete, in spite of the original specification that floors were not to be installed in the basement. The load of the platform legs on the floor reinforces that the floors are concrete. The timing of the concrete installation cannot be determined from the historical records available but could have been part of the radium separation lab construction. The fact that surface contamination exists on the current concrete floor supports the conclusion that the concrete floors were installed in this area prior to operations using radium.

PLATE No. 1. LEACHING POTS, BOXED, AND SUCTION FILTERS.

Figure 2-2: Stoneware Leaching Pot and Suction Filter Arrangement

The acidic solutions were precipitated in elevated 110-gallon conical stoneware pots. A large cast iron kettle was used for cooking ore with concentrated sulfuric acid and sodium bisulfate.

<u>Alkali Treatment Equipment</u>
Most of the processes using alkali leaches on the ore were conducted under pressure using an autoclave. The autoclave was a 50-gallon seamless steam-jacketed cast iron kettle with a bolted lid equipped with a stirrer attached to a driving mechanism. The autoclave was capable of being operated pressurized or under vacuum. In addition to the jacket, steam could be supplied directly into the top or bottom of the autoclave. The bottom of the autoclave was piped directly to a plate and frame filter press with eighteen 18” x 18” square plates. This allowed the autoclave to charge the press. The press was equipped for backwashing and air drying. A small steam pump was connected into the press supply line to force wash water through the press when charged. The press was mounted on an elevated platform to allow gravity feed of discharges into a series of four wooden tanks with capacities of 204 gallons (2), 316 gallons, and 444 gallons. The tanks were elevated about one foot as shown in Figure 2-2 and slightly tilted to accommodate complete draining. Steam, air, and water were available to all tanks. A one-inch iron steam injector was installed to transfer solutions between the tanks.

The layout of the autoclave and filter press is presented in Figure 2-3. Note that the photo is looking northwest and the window in the current mechanical room 13 is shown at the left side of the photo. The location of the cast iron support column aids in determining the exact location of the equipment relative to the current room configuration. It is evident in the photo that the first-floor joists and beams were not covered at the time.

A smelting furnace heated with an oil blast burner was used for roasting ores. See Figure 2-4. The furnace was equipped with rotating and tilting mechanisms and was designed to operate at a much higher temperature than was needed for the experiments, so it was difficult to maintain temperatures low enough. The air blast was so strong that the ore was reportedly continually blown out the back end of the furnace. Figures 2-2, 2-3, and 2-4 also show what appears to be a concrete floor.

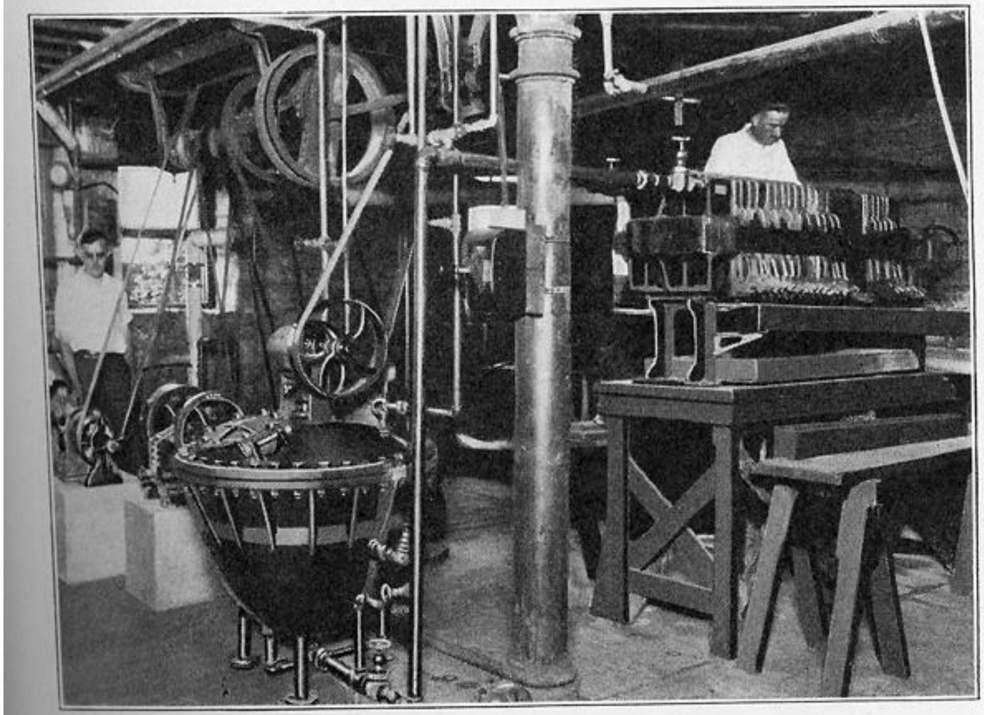

PLATE NO. 2. AUTOCLAVE AND FILTER PRESS.

Figure 2-3: Autoclave and Filter Press Arrangement

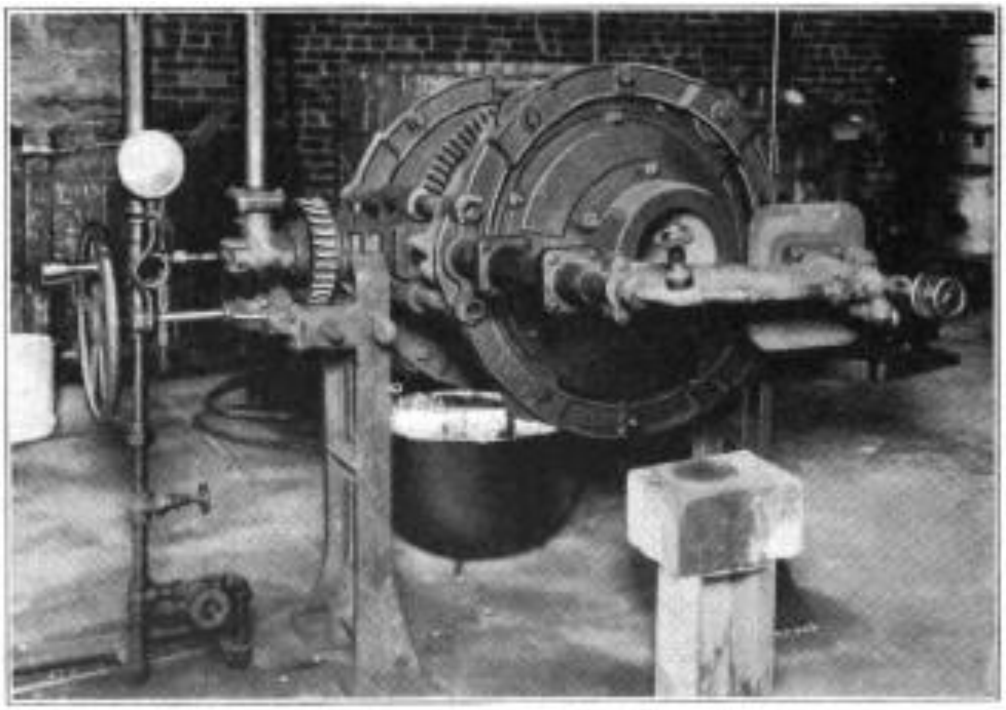

PLATE NO. 3. SMELTING FURNACE.

Figure 2-4: Smelting Furnace Looking Northeast

<u>Crystallizing Equipment</u>
One of the smaller rooms in the basement was used for crystallization. There is considerable uncertainty regarding which room was used, but it is suspected that it was room 27. Evaporation of plant liquors with radium and barium chlorides and the earlier fractionations were conducted in a series of glass enameled evaporators consisting of two 10-gallon steel pots and three 10-gallon cast iron pans loaned by the Welsbach Company as shown in Figure 2-5.

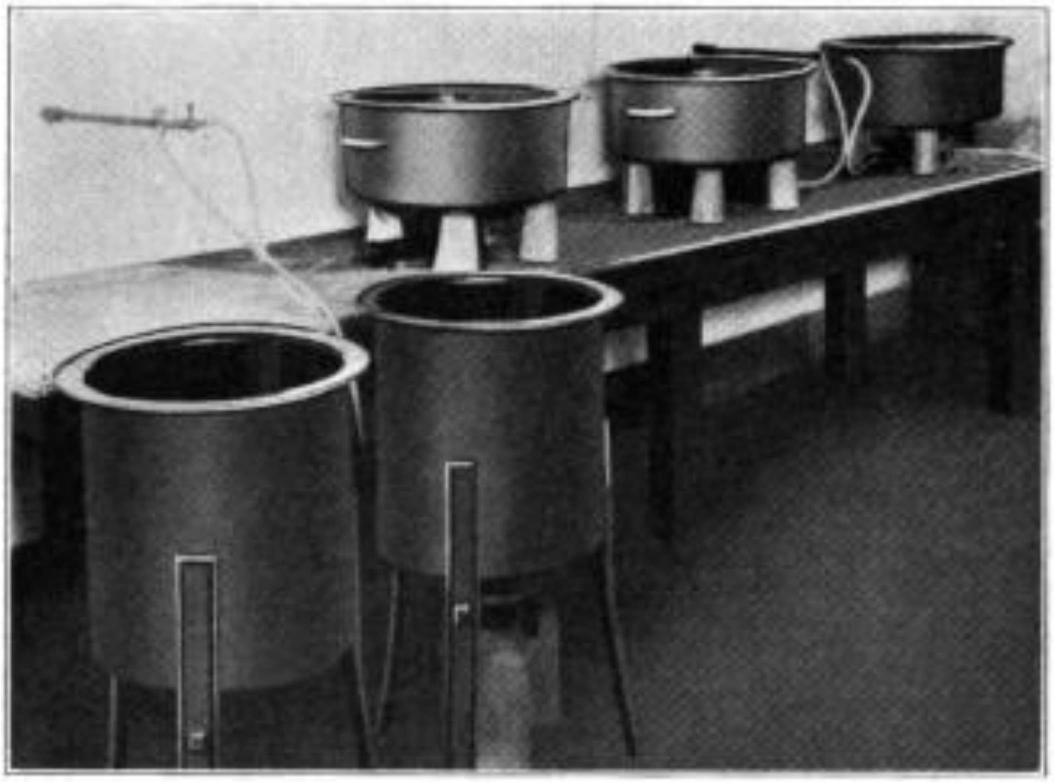

PLATE NO. 4. STEEL AND CAST IRON, GLASS ENAMEL EVAPORATORS.

Figure 2-5: Evaporators

As the radium concentrations increased during the crystallization process, large porcelain evaporating dishes graduating to smaller sizes were used. After conversion into bromides, porcelain dishes were used for a time, but fused silica ware was used for most of this work. Crystallizing equipment is shown in Figure 2-6. Small transparent silica dishes were used for fractionation of very high-grade bromides, and the dissolution and evaporation were conducted in a water bath.

PLATE NO. 5. BROMIDE CRYSTALLIZING SYSTEM.

Figure 2-6: Crystallizing Equipment

3.0 FACILITY DESCRIPTION

3.1 Site Location and Description

Pickard Hall is located at 405 S. Ninth Street, Columbia, Boone County, MO 65211-1420 in the Francis Quadrangle area, between the Chancellor's Residence to the south and the Reynolds Journalism Institute to the north.

The building has a footprint of 8,400 square feet with approximately 24,600 gross square feet of floor area over three elevations (not including an attic). The brick building sits on a stone and mortar foundation. The exterior of the building is shown in Figure 3-1 and Figure 3-2.

Floor plans showing the current building arrangement are provided in Appendix B. Floors on the first and second elevations are primarily carpeted with stone/ceramic tiled foyers and restrooms. Interior load bearing walls are brick (covered with plaster or sheetrock), other interior walls are framed with plaster or sheetrock coverings. The interior of the facility underwent a major renovation in 1974 that resulted in minor changes to the layout of the basement. Some windows on the basement and first floors and all windows on the second floor were covered on the inside to prevent ultraviolet damage to museum artifacts. The entire ventilation system has been upgraded since the cessation of usage of radioactive materials; some original ventilation shafts remain, but none are believed to have been in use since the upgrade. Original drains were terminated at floor level and grouted.

Figure 3-1: Pickard Hall – Looking Southeast

Figure 3-2: Pickard Hall – Looking Southwest

Like many other buildings at MU, Pickard Hall is serviced by the MU steam tunnel system. For Pickard Hall, this steam tunnel is located under the north/south sidewalk on the west side of the building. The feeder tunnel is perpendicular to the steam tunnel and connects the steam tunnel to Room 15 in the Pickard Hall Basement. A figure showing the feeder tunnel and the steam tunnel in relation to the Pickard Hall is provided in Figure 3-3.

Figure 3-3: Arrangement of Tunnels

The feeder tunnel interior dimensions are 3.2 feet (ft) wide by 15.5 ft long. A 3.2 ft by 8.3 ft area adjacent to Pickard Hall has exposed soils; there is no structural floor in this area. There are four concrete steps from the feeder tunnel to the steam tunnel. A 12 inch diameter pipe is embedded in the top step.

The steam tunnel has a brick floor where it connects to the feeder tunnel and changes to concrete 78 ft north of the feeder and 6 ft south of the feeder. Portions of the brick walls and floors are covered with a thin layer of concrete. The floors of the steam tunnel have approximately six inch wide, one inch deep concrete gutters along each wall. There is no structural information regarding the tunnel wall footing design or depth below the floor.

The bottom of the steam tunnel floor is 3.3 ft below the bottom of the Pickard Hall basement floor slab in Room 15. A cross section of the tunnels showing the elevation changes is presented in the figure below.

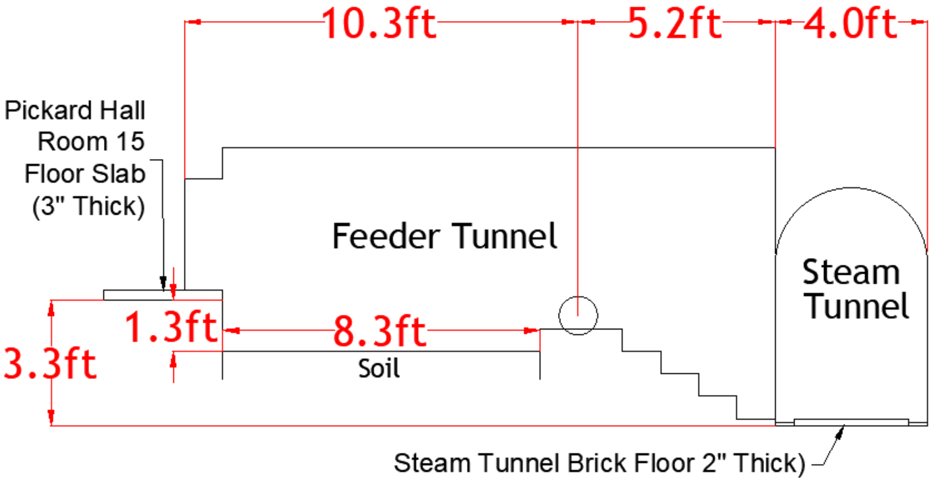

Figure 3-4: Tunnel Cross Section (Looking South)

The tunnels are designated as non-permit required confined spaces. Photos of the tunnel interiors are provided below.

Figure 3-5: Steam Tunnel (Looking South from Feeder Tunnel Entrance)

Figure 3-6: Steam Tunnel Interior (Looking North from Feeder Tunnel Entrance)

Figure 3-7: Pickard Hall Feeder Tunnel (View from Pickard Hall Room 15)

Figure 3-8: Pickard Hall Feeder Tunnel (View from the Steam Tunnel)

Detailed descriptions of the initial building construction and renovations are provided below.

3.2 Construction and Renovation History

3.2.1 Initial Construction

After Academic Hall burned in 1892, funds were allocated for the construction of the six buildings of the Francis Quadrangle. A portion of the funding was allocated to the Chemistry Department but did not include funds to outfit the building with the necessary laboratory equipment, including fume hoods. The plans for the six buildings were selected from options that did not include a layout designed specifically for a chemistry lab. While the architect in charge of the project, M. Fred Bell, made some adjustments to better suit the needs of the department, the building was still constructed with design flaws that obstructed the building's ventilation and posed dangerous conditions for lab workers. "For example, there were two hoods with no opening into a ventilating shaft, and one shaft in the basement laboratory had been blocked off with masonry about a foot above the opening" (Nightingale, 1975). A letter from Professor Sidney Calvert, who began his career in the Chemistry Department in 1894, describes the critical ventilation problems, mentioning that at times fumes were so dense that he could not even see the length of certain rooms. He goes on to report that over the course of the prior two years, he knew of seven men being carried out of the building unconscious as a result of inhaling the suppressed fumes (Nightingale, 1975).

Original specifications indicated that there were no hard floors to be installed in the basement. Based on photographic evidence, however, at some time prior to separating radium, the basement floor areas where radium processing occurred were covered in concrete. Other portions of the basement may have had wooden flooring. The current basement floor, however, is entirely poured concrete. The specifications also included lead-based paint and two-ply tarred paper under the slate roof.

Ventilation equipment included a belt driven 70" diameter exhaust fan powered by a steam engine, steam heating coils in the basement ceiling, and brick supply and return shafts within the load bearing walls of the building.

Original floor plans are presented in Appendix C. Current room numbers are shown on the original floor plans for reference.

3.2.2 1911 Update of Building Electrical

Over the years, the building underwent a series of updates. In 1911, there was a movement by faculty to expand the electrical wiring to provide lighting in all spaces of the building. However, due to the cost of the project, it was resolved to "wire only a balance room and that the corridor on the second floor be lightened with a gas fixture. These gas lighting fixtures remained connected in all the laboratories and offices in the building until it was rehabilitated in the early 1940's" (Nightingale, 1975).

3.2.3 1940 Major Renovation

The Old Chemistry Building (Pickard Hall) underwent its first major renovation project in 1940. "During 1938-39 a special fund was set up for the purchase of laboratory equipment for all undergraduate chemistry sources and for faculty and student research. Plaster falling from the ceiling, crumbling wall plaster, and peeling paint on the grimy walls in the old chemistry building led to a careful and detailed inspection of the building. Not only was the wire mesh supporting the plastered ceilings rusting out, but the ancient and crumbling rubber and cotton 1893 insulation of the electrical wiring was a serious fire hazard. During 1939-1940 funds were set up for the complete renovation of the building, from the rotting wooden flooring in portions of the basement on up to the 20 foot ceilings on the second floor. The entire building was rewired, the old ceilings were torn out and replaced, crumbling plaster on the walls was scraped off, the walls and ceiling were re-plastered and repainted" (Nightingale, 1975).

3.2.4 1949 Fire and Related Safety Upgrades

Chemistry professors had been requesting fire safety upgrades that had been ignored until 1949 when a fire broke out in the basement laboratory and the fire department was called to the scene. The fire caused little damage, but triggered fire safety improvements, including structural modifications to facilitate safe exit from the building. In 1951 "the west 7 feet of the two offices on the north end of the building were partitioned off to extend the halls, and fire doors leading to metal fire escapes were installed at the north ends of the halls on both floors. The wooden stairs from the basement to the second floor had been replaced by concrete stairs and a new door was installed at the ground level landing of the stairway on the east side" (Nightingale, 1975.)

3.2.5 1965 Ventilation Upgrades

In 1965, the ventilation ducts in rooms 3, 4, 10, 12, 203, 204, 210, and 212 were overhauled to allow proper airflow.

3.2.6 1970 Structure Assessment

In 1970, Wm. C. E. Becker, consulting Engineer, performed a condition assessment of the building. He indicated deterioration of mortar in basement walls, overloaded cast iron columns, timber joists loaded to maximum safe capacity, bearing issues where the steel beams and wood joists meet, and cracked ends of wood timbers. His conclusion was that the building was structurally sound but not economical to bring to current code, so he recommended replacing with a new building.

3.2.7 1974 Major Renovation

In 1972, the final remnants of the Chemistry Department moved out of the Old Chemistry Building (Pickard Hall) and into the new Chemistry Building. The Old Chemistry Building's architecture with large and small rooms and high ceilings appealed to the university's Art History and Archaeology Department as the new location for the Museum of Art and Archaeology. In 1974 the University began a major renovation project with the goal of updating the interior without negating the vintage atmosphere of the historic building, along with minimally altering the exterior of the structure (Mosher, 1974).

In order to stay within the allotted budget, architects and contractors had to focus primarily on the first and second floors. Listed below are the contract specifications of the 1974 interior and exterior renovations (Mosher, 1974).

- addition of an entry ramp on the south end of the east side for wheelchair students and new areaways for exit stairs from the basement level
- addition of concrete to areaway walls, stairs, ramps, equipment slabs, and elevator pit
- demolition and patching for new doorways and openings and a new elevator shaft wall
- removal of two columns in the lecture room and supporting the structure above with two beams, and all lintels, handrails and removable stairway
- repair of existing joists where ends had split, reworking of window sash to receive new glass, new sub-floor on the first and second floors, new lecture hall risers, new partitioning, and closing of windows
- caulking and thermal insulation of exterior walls
- new glass for all windows remaining open, glass to be insulating type for first and second floors and plate glass for basement windows, all windows to be fixed. All interior doors to be solid core wood, new entry doors to be glass, new exit doors to be hollow metal.
- seal basement concrete floors
- carpet first floor, except brick pave corridor and toilets
- carpet second floor
- paint over plaster or drywall in basement and on first floor
- carpet second floor gallery walls and paint other walls
- install drywall or acoustical tile ceilings as areas required in basement and on first floor
- install special ceiling systems for display purposes on the second floor
- install toilet partitions and accessories with provisions for paraplegic persons, firefighting device, and chalkboards in classrooms
- install unit kitchen and painting storage racks
- install fixed seating in lecture hall
- install one security vault
- install three-stop hydraulic elevator

- complete mechanical and plumbing systems for the building
- install lighting and power systems, security detection system, and fire detection system

As part of the 1974 renovation, new stairs were installed on the east end of north side of the building, causing a window and associated light well to be removed. Also, existing plaster was patched/repaired and 1-1/2" of lightweight concrete was placed over existing construction (tongue and groove wood flooring) on the 1st and 2nd floors.

3.2.8 1987 Roof Work

In 1987, MU removed paint and repainted metal roof components including ridge caps, hip caps, valleys, finials, fascia, cornice work, and downspouts. Damaged components were replaced and several new downspouts were installed.

3.2.9 1990 Fume Hood Exhaust Installation

In 1990, MU installed a stainless steel exhaust duct with pneumatic electric damper at a fume hood in basement room 18 and two flexible exhaust ducts in room 17, tying into the existing exhaust duct.

3.2.10 1993 Ramp Replacement

The ramp to the basement on the south end of the east side was removed and replaced in 1993.

3.2.11 1997 Foundation Project

In 1997, a major excavation and renovation was performed around the building's foundation. To support this work much of the building's exterior ground level fixtures and fittings had to be demolished. Concrete stairs on the northwest corner and associated side walls, drains, footings and slabs were removed entirely. Original exterior stone and concrete window wells were removed. Many original drains were removed entirely, but some underground lines were abandoned in place and capped. A French drain system was installed around the building adjacent to the stone foundation consisting of a PVC drainpipe 3.5 ft below grade within a 2 ft wide by 4 ft deep bed of 3/8 inch clean granular fill which was then covered with 18 inches of topsoil.

3.2.12 1999 Exterior Renovation

A renovation was performed primarily to the outside of the building and the slate roof in 1999. Windows and their frames were either refurbished or replaced, along with the exterior doors. Doors that were not fully replaced were stripped and repainted. The northernmost door on the west side of the building's first floor was sealed shut and dummy hardware installed. All roofing was removed to the wooden deck including the two-ply tarred paper under the slate. Slate and bituminous roofing materials were removed and replaced as well as gutters and downspouts along with installation of a new underground drain for the spouts. The wooden ladder that led from a tower window to the roof was removed. Also, the lead paint from the fire escapes was removed and the fire escapes repainted. The exterior brick was cleaned and damaged decorative bricks were removed and replaced. Stairs and entryways were revamped with new cement over existing stairs, along with the installation of new railings. The sidewalk adjacent to the new stairs was also re-cemented. Electrical circuits were extended and new light fixtures and switches were installed.

3.3 2014 Building Condition Assessment

The structural condition of the building was a major factor in determining the path forward for demolishing Pickard Hall and seeking unrestricted release of the site. While a comprehensive building demolition assessment will be performed during demolition planning, a preliminary building condition assessment was performed in 2014.

Representatives of consulting firm Trabue, Hansen, & Hinshaw, Inc. (THH) conducted a structural inspection of the building on April 8, 2014, to the extent that they could without performing invasive activities. This restriction caused THH to rely heavily on comparisons to similar buildings on campus that were constructed at the same time and by the same architect. This led to more than the usual number of assumptions. THH stated that the building was in remarkably good condition and that it was well maintained. While the building is stable in its current condition, any activity that would disturb the current geometric and loading arrangement (such as radioactive remediation activities) could be detrimental to the structural integrity.

3.4 Population Distribution

Pickard Hall is located within the Francis Quadrangle at the center of the MU campus. The building is surrounded by campus buildings that include academic, administrative, and housing facilities. Commercial businesses consisting mainly of restaurants are located across 9th Street, east of Pickard Hall.

As of the 2020 census, the population of Columbia was 125,691 with 49,666 households in the city. The population density was 1897.5 inhabitants per square mile.

3.5 Current/Future Land Use

The facility is currently located within MU campus in the historic Francis Quadrangle. The property will remain part of the campus for the foreseeable future, and the current plan is to construct another building in Pickard Hall’s place.

3.6 Meteorology and Climatology

The Columbia climate has sharp seasonal contrasts in temperature, falling between a humid continental and humid subtropical climate. The city is located within US Department of Agriculture (USDA) Plant Hardiness Zone 6a.

The monthly average temperature ranges from 30° F in January to 77° F in July, while the high reaches or exceeds 90° F an average of 32 days per year and 100° F on 2 days per year; sub 0° F lows occur an average of 4 days per year.

Precipitation tends to be greatest and most frequent in the latter half of the spring season, when severe weather is most common. Precipitation data for the months of May through October for 2018, 2019 and 2020 indicate that the average rainfall per year over this period is 3.1 inches, 4.6 inches and 4.3 inches, respectively. However, individual rainfall events have reached up to 5.8 inches over a 24-hour period. Snow averages 18 inches per season, mostly from December to March, with occasional November and April snowfalls. Historically seasonal snow accumulation has ranged from 3.4 inches in 2005–06 to 54.9 inches in 1977–78. Individual snowfall events are not material to the PHDP because the decommissioning activities are planned for the summer months during the lull in the regular academic schedule.

3.7 Natural Resources

There are no natural resources affected by this site decommissioning.

3.8 Geology and Seismology

Boone County varies in topography from relatively flat uplands to rather rugged hills. The exposed rocks range in age from Upper Ordovician to Pleistocene, but the Silurian and Permian periods, and the Mesozoic Era, are not represented by sediments in the county. Much of the area is mantled by glacial drift. The geologic structure is relatively simple and the Brown’s Station anticline is the only structure of prominence in the county.

The New Madrid fault lies to the southeast of Columbia, MO, at a distance of approximately 220 miles. This is the closest seismic area to the site with recorded seismic activity. Seismic activity in the Midwest is less frequent than the west coast.

3.9 Surface and Groundwater Hydrology

3.9.1 Surface Water

Site topography slopes minimally from east to west with Ninth Street being approximately four feet higher in elevation than the Pickard Hall grounds. There are various storm drain inlets around the building to carry away surface waters. Historically there have been issues with water infiltration into the Pickard Hall basement due to poor drainage of surface water. There has not been a water infiltration issue since the 1997 foundation project when a French drain system was installed around the building.

There are no bodies of surface water in the area of Pickard Hall that could be impacted by decommissioning activities.

3.9.2 Groundwater

Site groundwater hydrology information is based on data obtained from Engineering Surveys & Services (ES&S) located in Columbia, MO from a 2004 geotechnical investigation at the adjacent Journalism Building. The data are summarized in the ES&S report "Geotechnical and Hydrological Report," dated March 11, 2020.

3.9.2.2 Drinking Water Aquifer

MU operates its own Public Water System (PWS), separate from the City of Columbia. The 2021 Annual Water Quality Report (also known as the Consumer Confidence Report or CCR) for MU's PWS states that potable water is from groundwater extracted through five wells. While not included in the publicly available CCR, the five wells access the same groundwater aquifer and have an average well depth of 1,370 feet below ground surface (bgs). There is no known credible scenario for migration of radioactive contamination from Pickard Hall down the 1,300 vertical feet to this drinking water aquifer; characterization sampling demonstrates that residual radioactivity has migrated in soils to less than a few feet below the Pickard Hall basement slab.

3.9.2.2 Perched Groundwater

For the immediate vicinity of Pickard Hall, ES&S summarized hydrology information from their field logs of borings near Pickard Hall. Specifically, two borings were located between Pickard Hall and the Journalism Building to the north. Other borings were located on the northern side of the Journalism Building. The ES&S groundwater hydrology information, along with Figures showing the location of these borings, is provided in the report "Geotechnical and Hydrological Report," dated March 11, 2020.

As ES&S describes in their report, isolated areas of "perched" groundwater (i.e., wet soils) were encountered at depths of 15 ft bgs and 18-ft bgs at two borings between Pickard Hall and the Journalism Building. ES&S noted that perched groundwater depths are expected to vary seasonally and with environmental conditions. These perched water levels correlate to about 7 ft below the Pickard Hall basement floor slab. There are no potable water wells or any other known uses of water from the perched groundwater beneath MU.

ES&S provided typical data ranges for each of the following parameters and descriptions of the soils it collected from borings:

Unsaturated Zone:	Saturated Zone
Thickness	Soil Density
Soil Density	Total Porosity
Total Porosity	Effective Porosity
Effective Porosity	Field Capacity
Field Capacity	Hydraulic Conductivity
Hydraulic Conductivity	Water Table Drop
	Direction of Groundwater Flow

Based on existing characterization data beneath the Pickard Hall basement and tunnel floors, discussed below, soil impacts are bound above the level of the perched groundwater.

4.0 RADIOLOGICAL STATUS

4.1 Radiological Assessments

4.1.1 Initial Radiological Assessments

MU procured Chase in 2009 to survey accessible surfaces of the facility to the extent possible without interfering with museum operations (without moving artifacts, causing excessive vibration, etc.). Surveys were performed to determine the extent and magnitude of residual radioactivity to support decommissioning planning, and to evaluate radiological exposures to building occupants and visitors. The survey was an iterative process that was performed from December 2009 to October 2011 over six separate mobilizations.

Chase surveyed accessible portions of the entire facility including the basement, first floor, second floor, the attic, the roof, steam tunnel feeder, and outside grounds. Surveys consisted of the following types of measurements:

- indoor surface scans for alpha and beta emissions using gas flow proportional detectors (100% of accessible surfaces < 2 m height)
- indoor surface scans for gamma emissions using a 2” x 2” sodium iodide detector at a distance of 10 cm (100% of accessible surfaces < 2 m height)
- indoor large area wipes for alpha and beta removable activity (100% of accessible floor surfaces)
- at locations of elevated activity identified during indoor scans:
    - static measurements for alpha and beta total surface activity
    - static measurements for gamma emissions at a distance of 10 cm
    - external dose rate measurements at a 1 meter distance
    - disc smears for alpha and beta removable activity
- solid samples of concrete surfaces for gamma spectroscopy analysis (a subset of samples was also analyzed by alpha spectroscopy analysis)

- solid samples of contaminated brick ventilation shafts and wood flooring in the attic
- Global Positioning System (GPS) correlated gamma scans of outdoor areas
- surface soil samples for gamma spectroscopy analysis (a subset of samples was also analyzed by alpha spectroscopy analysis)
- sampling for airborne radioactivity

Results indicated that residual radioactivity existed in the following locations:

- on basement concrete floor surfaces that are covered with vinyl tiles
- on concrete floor surfaces in basement mechanical rooms that were subsequently encapsulated with a sprayed-on fixative
- in the steam tunnel feeder adjacent to Mechanical Room 15 where the top foot of soil was removed, and remaining soils covered with geotextile and pavers
- in certain buried drain lines under the basement floor
- on a former wooden window header under the stage in Room 106 that is also detectable in the basement ceiling in Room 1B
- in a small area inside a wall in Room 213 at a covered window location
- on floor surfaces in Rooms 205 and 206 that are carpeted
- in the attic on one small location on the floor and in open joist areas
- in the attic under floor decking
- inside brick ducts (assumed to be fume hood exhaust ducts) that are open in the attic
- in surface soils immediately outside the northwest corner of the building

In the initial assessments, there was extensive information regarding residual radioactivity on accessible surfaces, however, there was limited information regarding the following because the building was occupied and invasive sampling was not possible:

- extent of contamination on original surfaces inside the building that were covered (brick, plaster, etc.)
- subsurface soil concentrations
- impact to load-bearing structures
- impact to roof decking
- impact to stone and mortar foundation

As part of the 1974 renovation into a museum, interior walls were framed and covered to isolate original building surfaces and windows. The central stairwell from the 2nd floor to attic was removed and an elevator was installed. The elevator does not go to the attic, so a ladder was installed in Room 215 for attic access. The current auditorium was a lecture hall and may have had laboratory fixtures for demonstrations. During the 1974 renovation, the cast iron columns in the lecture hall (Room 106) were removed and replaced with structural beams that were pocketed into the load-bearing walls. The corresponding 2nd floor columns are still in place but have been framed in and covered with sheetrock. Stadium style seating was installed over the original Room 106 hardwood floors. These floor surfaces were accessed and surveyed to the extent possible during Chase surveys with no residual radioactivity identified.

Previous renovations likely remediated a significant number of impacted surfaces and structures. Ceilings and basement wood flooring were removed as part of the 1940 renovation, and roof coverings were removed and replaced in 1999.

Detailed results of the initial radiological assessment can be found in the reports "Pickard Hall Characterization Survey Report," dated July 16, 2010,[1] that describes Phases 1 and 2 of the assessment and "University of Missouri Pickard Hall Phase III Characterization Survey Report," dated October 17, 2011.

4.1.2 Pre-Decommissioning Characterization

During a meeting with the NRC in February 2020, and as documented in its letter of March 12, 2020,[2] the NRC requested additional information regarding radiological site conditions. The additional characterization activities and offsite laboratory analyses were performed from May 2020 to November 2020, with contemporaneous notifications and discussions between MU, Chase, and NRC Staff.

The following is a summary of the activities completed.

- Basement Activities
    - Removed basement interference
    - Abated asbestos-containing material (ACM) floor tile
    - Removed framed walls and ceilings in Room 1 and Room 12
    - Removed the bottom portion of a wall separating Room 17 and 17A
    - Performed characterization surveys on newly exposed surfaces
    - Performed gamma scans of the floors and walls to identify any locations of elevated gamma emissions
    - Scarified concrete surfaces in some basement areas to reduce background radiation levels for determining subsurface soil sampling locations

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[1] Pickard Hall Characterization Survey Report (July 16, 2010) (ML102800579).

[2] Letter from M. LaFranzo, NRC, to T. Houts, MU, Acceptance Review of Decommissioning Plan Submitted in Accordance with 10 CFR 30.36(g) Under License No. 24-00513-32 (Mail Control No. 596692) (Mar. 12, 2020) (ML20078L134).

  - Cored the basement floor slab and collected underlying soil samples from planned and discretionary locations for off-site laboratory analysis
  - Encapsulated locations of elevated surface activity
- 1st and 2nd Floor Activities
  - Accessed and surveyed the window frame area in Room 213
  - Collected core samples from identified locations of elevated activity on the 1st and 2nd floors for off-site laboratory analysis
- Exterior Activities
  - Performed GPS gamma scan of the grounds surrounding Pickard Hall and the background reference area
  - Collected subsurface soil samples from grounds surrounding Pickard Hall and the background reference area for off-site laboratory analysis
- Attic Activities
  - Provided radiological support for MU to construct scaffolding for safe means of accessing the attic
  - Removed and packaged fiberglass insulation waste
  - Vacuumed residual dust and debris from between the floor joists
  - Performed gamma scans and gas flow proportional scans to identify locations of residual radioactivity
  - Encapsulated attic surfaces with residual removable radioactivity to affix the activity
  - Performed characterization surveys of ventilation chimneys

4.1.3 Tunnel Subsurface Soils Characterization

The Pre-Decommissioning Characterization was augmented with data collected during a tunnel subsurface soil sampling effort conducted in January 2022, after a structural evaluation of the tunnels determined the limitations and safe extent of the sampling effort. Work was performed according to the “University of Missouri Pickard Hall Tunnel Subsurface Soil Sampling Radiological Work Plan” dated November 19, 2021. Work Plan activities were designed to collect sufficient data to determine radiological impacts to soils below the feeder tunnel and the steam tunnel in the vicinity of Pickard Hall. The following tasks were performed:

- Confirm that there is no structural floor in the feeder tunnel
- Survey structural surfaces in the steam tunnel and feeder tunnel
- Select subsurface soil sample locations on the steam tunnel and feeder tunnel floors based on survey results, structural considerations, and utility locations
- Sample soils in the feeder tunnel floor
- Core through the steam tunnel floor and sample underlying soils
- Send samples to the external laboratory for gamma spectroscopy (Ra-226) and alpha spectroscopy (U and Th) analyses

4.2 Building Structures and Systems Contamination

Between May 2020 and January 2022, Chase supplemented the data from the initial radiological assessment by performing intrusive sampling and measurements throughout Pickard Hall interiors and in surrounding soils. Characterization surveys indicate that residual radioactivity exists on the following structural surfaces:

- Steam tunnel and feeder tunnel
- Basement
    - Concrete floors and brick walls
    - Room 1 and Room 12 overhead surfaces
- 1st Floor
    - Room 106 under raised floor and lectern area
    - Room 111 walls assumed to be associated with a ventilation chimney
- 2nd Floor
    - Room 213 wall and floor
    - Room 205 wall, assumed to be associated with a ventilation chimney, and floor
- Attic - various locations on wood planking and ventilation chimneys

Removable radioactivity on the floors and walls throughout most of the building has been encapsulated. The ventilation chimneys in the attic and some locations in the basement will be encapsulated prior to demolition. A summary of the surface activity measurement results prior to encapsulation is provided in Table 4-1. Total alpha + beta surface activity measurements were performed with Ludlum 43-68 and 43-37 gas flow detectors and removable surface activity measurements were performed with Ludlum 43-10-1 detectors.

Table 4-1: Summary of Surface Activity Measurement Results Prior to Encapsulation

Room	Surface	Surface Activity (dpm/100 cm^2)	
		Total Alpha + Beta	**Removable Alpha**
Basement East Corridor	Floor	74 – 13,066	up to 14
Basement Southwest Corridor	Floor	208 – 57,404	up to 8
1	Floor	61	<MDC
1	South soffit	4,297 – 11,840	up to 37
1	North soffit	1,115 – 1,509	up to 20
1	Ceiling between soffits	317	<MDC
7	Floor	68 - 1,788	<MDC
9	Floor	191 – 21,622	<MDC

Room	**Surface**	**Surface Activity ($dpm/100\ cm^2$)**	
		Total Alpha + Beta	**Removable Alpha**
10	Floor	89 – 2,102	<MDC
11	Floor	<MDC	<MDC
12	Floor	194 – 167,832	up to 194
12	North wall	3,835 – 111,943	up to 307
12	East wall	up to 4,507	up to 210
12	South wall	up to 1,898	up to 211
12A	Floor	435 – 48,055	up to 4
13	Floor	286 – 13,984	<MDC
13A	Floor	212 – 2,157	<MDC
15	Floor	3,097 - 8226	<MDC
16	Floor	up to 580	<MDC
17	Floor	233 to 2,055	<MDC
17A	Floor	57 – 7,606	<MDC
18	Floor	up to 286	<MDC
18A	Floor	<MDC	<MDC
20/21	Floor	436 – 3,394	<MDC
23	Floor	1,620	<MDC
25	Floor	<MDC	<MDC
26	Floor	87 – 6,877	<MDC
27	Floor	488 – 8,859	<MDC
28	Floor	55	<MDC
28A	Floor	158	<MDC
213	Floor and window opening	141 – 6,774	<MDC
Attic	Floor	305 – 9,908	up to 48
Attic	Chimney 14	11,226	up to 8
Attic	Chimney 15	48,250	up to 179
Attic	Chimney 16	21,325	up to 276
Attic	Chimneys 1-13, 17-20	202 – 1,788	up to 6
Steam Tunnel	Floor and gutters	2,346	<MDC
Steam Tunnel	Gutter	4,426	<MDC
Steam Tunnel	Gutter	3,299	<MDC
Steam Tunnel	Gutter	1,410	<MDC
Steam Tunnel	Gutter	2,233	<MDC

Solid samples were collected on the 1st and 2nd floor and in the attic in areas of elevated gamma measurements. A summary of the solid samples collected with concentrations greater than expected naturally occurring radioactive material (NORM) concentrations is provided below.

Table 4-2: Solid Sample Location and Summary

Room	Feature Sampled	Ra-226 (pCi/g)
205	Wall (Plaster/Brick)	25
205	Floor (Wood)	10
205	Wall (Plaster/Brick)	20.3
Attic	Chimney (Brick)	8.2
Attic	Chimney (Brick)	42.3
Attic	Floor (Wood)	72.4

Characterization survey results can be found in the reports "Pickard Hall Pre-Decommissioning Characterization Report," dated December 11, 2020, and "University of Missouri Pickard Hall Tunnel Subsurface Soil Sampling Report" dated March 4, 2022.

4.3 Soil Contamination

4.3.1 Surface Soils

During the initial radiological assessment in December 2009, surface soil samples were collected at four discrete locations in outside grounds surrounding the building. Two of the samples were at small (up to a few square feet) areas of elevated activity detected by a sustained increase in the count rate during gamma scans. Six background surface soil samples were collected in the Quadrangle. Gamma spectroscopy results were used to select a subset of three background samples and three soil samples for uranium and thorium isotopic analysis by alpha spectroscopy.

The two small areas of elevated surface activity (47 and 18 pCi/g Ra-226) were identified in the outside grounds located several feet away from the building outside the northwest corner of Room 16. The locations were excavated to a one-foot depth and a sample was collected at the bottom of each excavation. Sample results dropped to below 6 pCi/g.

After removal of the two small areas of surface soil with elevated activity, outdoor gamma scans were performed in March 2010 using GPS mapping to provide visualization of surface gamma radiation levels. Several areas of elevated activity were identified on the GPS map, all of which were attributed to naturally occurring radionuclides in granite markers and brick pavers, except for in the northwest corner of Pickard where elevated activity had previously been identified. It should be noted that, even though elevated radiation levels were identified, all of the more than 13,000 measurements were less than twice the background rate.

The information provided by the GPS survey provided input to the design of additional surface soil sampling locations. Nineteen additional samples were collected in May 2010 (two of the samples were a composite of four locations in the Quadrangle). Results were similar to background results. The highest result was 3.2 pCi/g Ra-226 and 1.4 pCi/g Th-232, U-238 was less than the MDC. The highest results for the background sample set were 3.27 pCi/g Ra-226 and 1.17 pCi/g Th-232.

Residual soil radioactivity up to 792 pCi/g Ra-226 was identified in the feeder tunnel that is located adjacent to the area where radium was historically extracted from ores. In March 2010, Chase removed approximately one foot of the soils on the feeder tunnel floor and covered the area with a geotextile fabric and pavers to provide a barrier from radioactive materials. These soils were subsequently characterized in January 2022 as described in Section 4.3.2.

4.3.2 Subsurface Soils

In August 2020, Chase sampled subsurface soils from the Background Reference Area located near Turner Garage, the exterior soils surrounding Pickard Hall, and the soils below the concrete slab in the basement of Pickard Hall.

Soil sampling locations were divided into two categories, planned (square grid locations) and discretionary. Exterior samples utilized a direct push probe with a 5-foot core interval. Interior below-slab cores were collected using a rotary hammer soil core with a 2-foot core interval. To determine discretionary sampling locations, Chase performed a gamma walkover survey of areas and underground utilities were located. Subsurface soil samples were then collected at a depth up to 15-ft bgs for exterior locations and up to 4 ft below the Pickard Hall basement concrete floor slab.

Soil cores were screened for radioactivity with portable handheld instruments prior to collecting samples in 1-foot sections. At least one sample from each depth interval was selected for analysis by Teledyne Brown Engineering and the remaining samples were archived at Pickard Hall for future analysis if needed.

Chase concluded that the residual activity in subsurface soils under the basement floor slab has been adequately bounded and is isolated to elevated areas under the slab in Rooms 12, 17A, and 27. The average concentrations, distribution of radionuclides, and summary statistics in subsurface soil samples exterior to Pickard Hall and in below slab soils outside of Rooms 12, 17, and 27 are within two standard deviations of the BRA average concentrations of 0.9 pCi/g Ra-226, 0.68 pCi/g Th-232, and 0.46 U-238. BRA maximum concentrations were 2.21 pCi/g Ra-226, 1.14 pCi/g Th-232, and 1.01 U-238.

For the soils below Rooms 12, 17A, and 27, Chase compared the concentrations to an investigation level (IL) equal to the average BRA concentration for each nuclide of concern plus two times the standard deviation, i.e., background plus 2-Sigma. The ILs for the nuclides of concern were 1.46 pCi/g for Ra-226, 1.21 pCi/g for Th-232, and 0.89 pCi/g for U-238. Thirteen samples in the 0-1 foot sample section depth were greater than the Ra-226 IL with the maximum elevated activity concentration at 487 pCi/g in Room 12, 37 pCi/g in Room 17A, and 4,664 pCi/g in

Room 27. The 1-2 foot sample depth in these rooms were significantly lower. A summary of the soil concentrations for soils below Rooms 12, 17A, and 27 is provided in the table below. These locations were selected because they exceeded the IL established for characterization. The concentrations are retrospectively compared to the soils DCGL in the table below to provide a direct comparison to dose-based criteria that was not available during characterization.

Table 4-3: Below Slab Locations Greater than Subsurface Soils DCGL[3]

Bore Location	**Depth Interval (ft)**	**Sample Results (pCi/g)**		
		Ra-226	**Th-232**	**U-238**
C000B01[4]	**0-1**	**4,664**	**2.18**	**1.18**
2702	**0-1**	**335**	**8.14**	**1.31**
	1-2	4.32	0.55	1.29
	2-3	7.27	0.90	0.97
2704	**0-1**	**4,206**	**7.00**	**2.40**
	1-2	**15.75**	**0.59**	**0.89**
17A1	**0-1**	**37.34**	**0.78**	**0.78**
	1-2	1.37	0.55	0.44
1203	**0-1**	**30.16**	**0.58**	**1.03**
	1-2	1.28	0.01	0.91
1202	**0-1**	**487**	**71.72**	**0.81**
	1-2	1.75	1.32	2.33

Subsurface soil characterization activity descriptions and results can be found in the "University of Missouri Pickard Hall Pre-Decommissioning Soil Data Report," Revision 1, dated November 30, 2020.[5] As explained in that Report, laboratory analysis shows a significant decrease of residual radioactivity from the shallowest to the deepest sample section analyzed at each of the below-slab locations, and the deepest sample sections were only within a foot or two of the shallowest sample section. Therefore, residual radioactivity in subsurface soils under the Pickard Hall basement floor slab have been adequately bounded.

In January 2022, Chase sampled subsurface soils in the steam tunnel and in the Pickard Hall feeder tunnel. Chase conducted gamma scan surveys with a 2" x 2" NaI detector to determine sample locations. Gamma scan results ranged from 6k cpm to 16k cpm north and south of the feeder tunnel access with five identified

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[3] Sample concentrations greater than the soils DCGL are in bold print.

[4] Boring location C000B01 was directly on top of the foundation footing for the wall and the doorway of Room 27. This boring location was abandoned after collection of the 1-ft section. Although identified as a corridor sample, location C000B01 is included in the designation of the Room 27 elevated area.

[5] Pickard Hall Pre-Decommissioning Soil Data Report, Rev. 1 (Nov. 30, 2020) (ML20344A404) (Package).

discrete locations of elevated activity markedly higher than the surrounding areas. All locations of elevated activity identified by gamma scans were on floor surfaces primarily within the gutters adjacent to the walls. Scans of walls and external surfaces of piping did not identify any locations of elevated count rate. Steam tunnel dose rates ranged from 5-10 µrem/hr north of the feeder tunnel access where the tunnel is constructed of concrete and 10-15 µrem/hr south of the feeder tunnel access where the tunnel is constructed of brick. Dose rates up to 30 µrem/hr were measured near the feeder tunnel access. Large area wipes on the steam tunnel structural surfaces had no detectable activity. The Pickard Hall feeder tunnel survey results were elevated due to the volume of contaminated soils on the floor. Dose rates in the feeder tunnel were 30-40 µrem/hr.

Soil samples collected in the feeder tunnel contained a higher fraction of Th-232 than in other areas previously sampled, and Th-230 was detected in significantly higher concentrations than U-238 indicating disequilibrium with the decay chain. The average fractions of nuclides in feeder tunnel soils based on soil sample analytical results at the locations of highest activity are 39% Ra-226, 25% Th-230, 25% Th-232, and 11% U-238. The higher fractions of Th-230 and Th-232 in this area is suspected to be from the material received from the Welsbach Company, a thorium mantle manufacturing facility, that was used at Pickard Hall for research involving Ra-228, as discussed above in Section 2.2.2.

Table 4-4: Feeder Tunnel Soil Sample Results [3]

Boring Location	**Depth Interval (ft)**	**Sample Results (pCi/g)**			
		Ra-226	**Th-230**	**Th-232**	**U-238**
FDR-001	**0-1**	**132**	**83.4**	**63.7**	**6.41**
	1-2	**21.2**	**25.8**	**16.3**	**3.33**
	2-3	2.23	2.29	3.11	2.69
	3-4	0.769	2.91	1.85	2.25
FDR-002	**0-1**	**60.1**	**27.0**	**28.7**	**3.75**
	1-2	8.48	3.03	4.24	2.47
	2-3	7.34	3.67	4.66	3.03
	3-4	1.05	2.57	1.77	1.89

Table 4-5: Steam Tunnel Soil Sample Results [3]

Boring Location	Depth Interval (ft)	Sample Results (pCi/g)			
		Ra-226	Th-230	Th-232	U-238
STM-001	0-1	0.96	1.33	1.20	1.13
	1-2	0.92	1.58	1.52	1.83
	2-3	0.89	1.19	1.36	0.90
STM-002	0-1	1.67	2.00	1.75	0.85
	1-2	0.97	1.94	1.38	1.59
STM-003	0-1	1.97	2.53	2.25	1.52
	1-2	0.65	1.07	0.81	0.70
	2-3	0.69	1.60	1.11	0.43
	3-4	1.52	1.72	1.10	2.05

Chase concludes that the residual activity in subsurface soils has been adequately bounded laterally and vertically. Tunnel subsurface soil characterization results can be found in the report "University of Missouri Pickard Hall Tunnel Subsurface Soil Sampling Report" dated March 4, 2022.

4.4 Surface and Groundwater

There are no surface bodies of water located on or near Pickard Hall.

As explained above, data from the Pre-Decommissioning Soil Data Report Tunnel Subsurface Soil Sampling Report demonstrates that residual radioactivity in soils is bound at depths above the nearest perched water table, and that the aquifer used by MU for potable water is located approximately 1300 feet below that. Therefore, there are no groundwater impacts that are being addressed in this Plan.

Any migration of radium compounds via a preferential subsurface pathway, such as pipe, conduit, and the Steam Tunnel, will be evaluated for residual radioactivity after demolition.

5.0 NUCLIDES OF CONCERN

Uranium and thorium bearing ores were brought into Pickard Hall in the early 1900's and chemically separated to remove Ra-226 from uranium ores and Ra-228 from thorium ores. These separation activities result in six different categories of potential contaminants:

- Natural Uranium (ore)
- Natural Thorium (ore)
- Separated Ra-226

- Separated Ra-228
- Uranium Tailings
- Thorium Tailings

Uranium ores contain the entire natural uranium decay series in secular equilibrium. Natural uranium contains uranium isotopes in the following abundances by weight; 99.3% U-238, 0.006% U-234, and 0.72% U-235 (these natural abundance levels correspond to total uranium activity fractions of approximately 48.3% U-238, 49.5% U-234 and 2.3% U-235). After ore is processed to chemically remove Ra-226, two separate materials result; Ra-226 and tailings. The separated Ra-226 will then decay and ingrow progeny. The remainder of the ore (tailings) includes all nuclides except the Ra-226 that was chemically separated.

Due to the half-lives of the progeny below Ra-226, the Ra-226 progeny in the tailings have decayed to insignificant levels. Characterization sampling results demonstrate that residual natural uranium and tailings are commingled in small fractions with Ra-226; therefore, for all practical purposes residual uranium exists at the site as natural uranium because the entire decay chain is present.

Thorium ores contain the entire natural thorium decay series in secular equilibrium. After ore is processed to chemically remove Ra-228, two separate materials result; Ra-228 and tailings. Due to the half-lives of Th-232 progeny and the time since separation, the separated Ra-228 has decayed to insignificant levels and the tailing stream has ingrown to secular equilibrium; therefore, only natural thorium (Th-232 in secular equilibrium with progeny) is of concern for decommissioning.

The processes of chemical separation, decay, and ingrowth results in the following nuclides of concern for decommissioning:

- Ra-226+C
- Natural Thorium (Th-nat)
- Natural Uranium (U-nat)

Nuclide ratios are based on gamma spectroscopy and alpha spectroscopy analysis of soil and concrete samples. High activity (>30 pCi/g) below-slab soil samples collected in 2020 have mean nuclide ratios of 95.8% Ra-226, 3.2% Th-232 and 1.0% U-238. Concrete samples from the floors in rooms 12, 13, and 17A collected in 2009 have mean nuclide ratios of 88.8% Ra-226, 8.6% Th-232 and 2.6% U-238.

The ratios associated with the concrete samples are used because a higher concentration of thorium is present, resulting in more conservative radiation protection procedures. Additionally, soil DCGLs are nuclide specific and nuclide-specific measurements will be performed for the final status survey (FSS).

The nuclides of concern and ratios for decommissioning planning are presented below.

Table 5-1: Nuclide Ratios

Nuclide	Fraction
Ra-226+C	88.8%
Th-nat	8.6%
U-nat	2.6%

As discussed above in Section 4.3.2, soil samples collected in the feeder tunnel contained a higher fraction of Th-232 relative to Ra-226 than in other areas previously sampled. Additionally, Th-230 was detected in significantly higher concentrations than U-238 indicating disequilibrium with the decay chain: this is suspected to be from material received from a thorium manufacturing facility that was used at Pickard Hall for research involving Ra-228. The average fractions of nuclides in feeder tunnel soils based on soil sample analytical results at the locations of highest activity are 39% Ra-226, 25% Th-230, 25% Th-232, and 11% U-238. Due to the limited scope of soil contamination in the feeder tunnel, the use of nuclide-specific DCGLs, and conservative air sampling methods, the feeder tunnel area nuclide ratios are not used to plan overall project decommissioning procedures. This area will be treated separately.

6.0 UNRESTRICTED RELEASE CRITERIA

The release criteria for unrestricted use are specified in 10 CFR § 20.1402, "Radiological Criteria for Unrestricted Use" which states that *"a site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent (TEDE) to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA). Determination of the levels which are ALARA must take into account consideration of any detriments, such as deaths from transportation accidents, expected to potentially result from decontamination and waste disposal."*

7.0 ALARA ANALYSIS

MU has decided to proceed with building demolition as recent renovations of similar era buildings nearby have cost substantially more than originally estimated due to the mitigation cost to safely handle structural integrity issues with the 120+ year old buildings. MU has determined that the costs of maintaining structural integrity of the building for the safe remediation and renovation is prohibitive.

Proceeding directly to building demolition also is in the best interest of safety for project personnel, staff, faculty, students, and the public.

MU has chosen a very conservative path for decommissioning intended to remove all building debris and contaminated soil and ship off-site for disposal. Building debris will be disposed as radioactive waste or clean demolition debris as appropriate. Demolition rubble will not be recycled. After removal of demolition debris and remediation of soils, remaining soils and adjoining structures such as the steam tunnel will be surveyed to demonstrate compliance with site-specific DCGLs.

MU will use typical good-practice efforts such as cleaning structures, remediating readily removable radioactivity, and other good housekeeping practices. The decision to remediate will be based on the goal of optimizing the proper balance between costs and benefits below the dose limit of 25 mrem/yr. MU intends to remediate residual licensed radioactive material that is distinguishable from background radioactivity during scan surveys; however, there may be situations where it is not feasible or is not ALARA, such as remediation that would impact the structural integrity of the steam tunnel, or require extensive excavation to remediate a slightly contaminated utility line. The decision to remediate will be based, at a minimum, on consideration of the potential dose averted, remediation cost, occupational safety risk, transportation safety risks, and public interest factors. For these reasons, a quantitative ALARA analysis is not required for this DP at this time. MU will evaluate whether conducting a quantitative ALARA analysis according to NUREG-1757, Volume 2, Chapter 6 and Appendix N is required after building demolition and post-demolition characterization are complete.

8.0 PLANNED DECOMMISSIONING ACTIVITIES

The objective of the PHDP activities is to remove licensed radioactive material from the site, obtain NRC approval to release for unrestricted use, and remove Pickard Hall from the MU broad scope license. Work performed during the decommissioning of Pickard Hall will be conducted in three phases in accordance with the following work plans:

- Phase 1, Demolition Plan
- Phase 2, Characterization Plan
- Phase 3, Remediation and Final Status Survey Plan

9.0 STOP WORK CONDITIONS

During execution of the PHDP, conditions that are materially outside the scope of the Plans will require work to stop, the work area will be placed in a safe configuration, and MU will notify the NRC. The affected work will not resume until the condition has been corrected and proper controls have been established.

Work re-start will be authorized by the Chase Radiation Safety Officer (CRSO) with MU Radiation Safety Officer (MURSO) concurrence. Work that is not affected by the stoppage may continue as long as continuance of work will not cause or exacerbate adverse conditions. If work is stopped due to an unanticipated weather condition, then work may resume when the weather condition no longer exists and it is safe to resume work.

NRC notification will be by phone and e-mail and will include, at a minimum, the following information:

- Reason(s) for stopping work
- Description of the circumstances leading to the work stoppage
- Actions taken to place the entire site (or affected portion of the site, as applicable) in a safe configuration
- Pertinent radiological data and any impact to worker doses, public doses, or releases to the environment
- Proposed corrective actions and timeline

10.0 SCHEDULE

After NRC approval, MU anticipates all decommissioning activities will be completed within 24 months of initiation. A conceptual project schedule is presented in Appendix D. The schedule includes NRC review periods; MU understands that approval of the Plans by the NRC is not a commitment to meet these estimated review times.

If severe weather or any other event (such as a pandemic) caused a force majeure type of delay, then MU would at that time invoke 10 CFR § 30.36(g)(4)(vi) and provide the appropriate justification for delay.

11.0 PROJECT MANAGEMENT AND ORGANIZATION

Licensed decommissioning activities will be performed under the Chase Commonwealth of Kentucky Radioactive Materials License 201-605-15 and associated Radiation Safety Manual (RSM) utilizing a reciprocal agreement with the NRC. For periods when no active decommissioning work is being performed, the site will be maintained under the MU Broad Scope radioactive materials license. Project management and business aspects of the project will be managed by MU Campus Facilities while environmental, health and safety aspects of the project will be independently overseen by MU EHS personnel.

MU and Chase are committed to maintaining a safe work environment while protecting the worker, the environment and the public. All PHDP personnel, regardless of their title, position or assignment, have a responsibility to work safely.

Every employee is empowered to halt or suspend operations if they perceive conditions or activities that are adverse to safety for themselves, their coworkers, the environment or the public. The management structure that will be utilized for administration and implementation of the PHDP is described below.

11.1 Decommissioning Management Structure

Decommissioning activities are implemented by the Chase Project Manager (PM) as contracted by the Director of MU Planning, Design, and Construction. The Chase PM is responsible for regulatory compliance and radiation safety during the performance of each task. The MURSO oversees Chase's implementation of the Radiation Protection Program (RPP) on each decommissioning task. The organizational chart is provided in Figure 11-1. Dashed lines are the radiation safety lines of authority; whereas, solid lines are reporting lines of authority. The demolition contractor will have a similar reporting relationship to MU Project Management with radiological oversight of demolition activities by Chase.

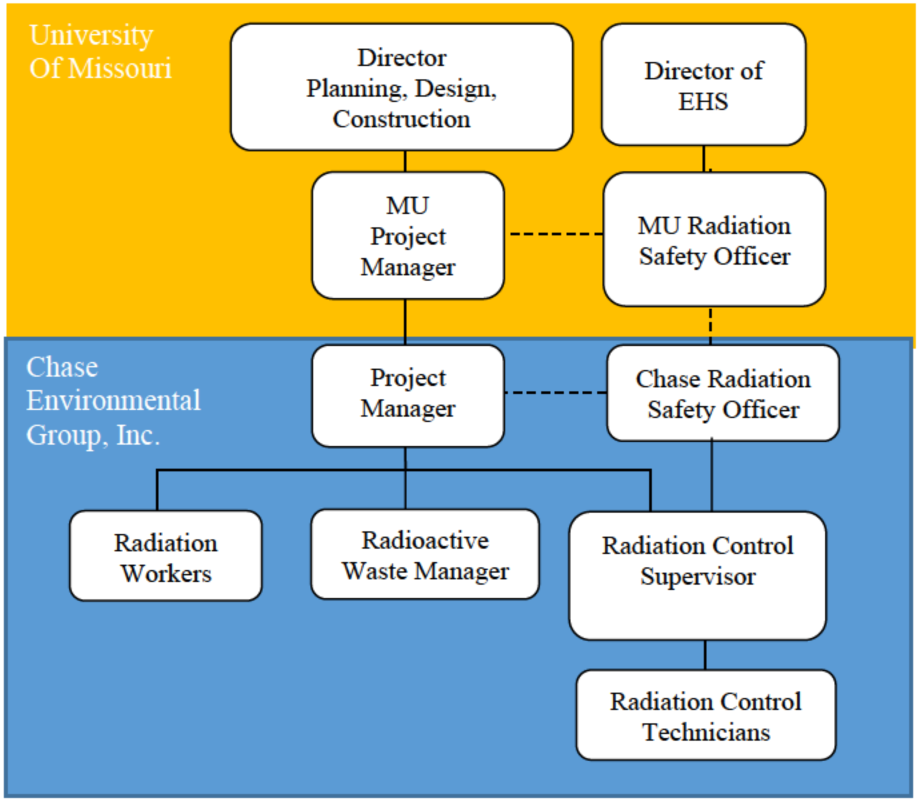

Figure 11-1: PHDP Organization Chart

11.2 Decommissioning Management Positions and Qualifications

Positions and qualifications of the decommissioning organization are described below. Personnel performing work at the site will meet the training and qualification requirements of the Chase RSM and be approved by the CRSO.

11.2.1 Director of MU Planning, Design, and Construction

The Director of MU Planning, Design, and Construction (MU CF-PDC) reports to the MU Assistant Vice President of Facilities, Planning and Design. The Director MU PDC maintains fiduciary and contractual responsibilities for the PHDP. Contractually, Chase reports to the Director of MU PDC via the MU Project Manager.

11.2.2 MU Project Manager (MU PM)

The MU PM has no direct radiation protection responsibilities. The MU PM reports to the MU PDC and is responsible for managing contractual aspects of the project; coordinating MU support; administering contracts; and tracking PHDP scope, schedule and budget performance.

11.2.3 Environmental Health & Safety Director

The MU EHS Director has overall responsibility for development and implementation of all MU EHS programs including occupational safety, radiation safety, industrial hygiene, biological safety, and environmental management. The EHS Director will ensure all EHS resources are available as needed to oversee project activities to ensure they are completed safely and compliantly.

11.2.4 MU Radiation Safety Officer (MURSO)

The MURSO is responsible for overseeing implementation of the PHDP radiation protection program by Chase and ensuring that PHDP activities do not result in a violation of the MU broad scope license. The MURSO has the responsibility and authority to stop any plan or activity that has the potential to result in an unacceptable radiological condition.

11.2.5 Chase Project Manager (Chase PM)

The Chase PM is responsible for task radiological operations from initiation through completion. The Chase PM reports to the MU PM for contractual obligations and to the CRSO for regulatory obligations. The Chase PM is responsible for daily implementation of the Radiation Protection Program (RPP). The Chase PM’s duties include the following:

- Maintaining working conditions which assure health, safety, and protection for all project personnel, visitors and the environment;
- Maintaining compliance with conditions of operating licenses, permits, rules, regulations and company procedures;
- Ensuring that employees are provided physical examinations as required by company policy, local, state and federal regulations;
- Ensuring that PHDP personnel are instructed regularly, or as required by law, on precautions, procedures and practices to be followed to minimize exposure to radioactive materials and to conduct operations safely;
- Notifying the CRSO and the MURSO promptly, of any operation or condition which appears to present a radiological hazard to PHDP

personnel, the public, the environment or exceed limitations set forth in the Radiation Safety Manual (RSM) or applicable procedures and work plans;

- Furnishing proper personnel protective equipment (PPE);
- Ensuring that PHDP personnel are instructed in the proper use of PPE and enforcing rules for the equipment's utilization;
- Ensuring the project has sufficient staffing to conduct daily operations in compliance with regulatory requirements; and
- Maintaining project radiation exposures ALARA.

11.2.6 Chase Radiation Safety Officer (CRSO)

The CRSO bears ultimate responsibility to manage and oversee radiological safety under the PHDP. The CRSO has the responsibility and authority to stop any plan or activity that has the potential to result in an unacceptable radiological condition. The following duties and responsibilities will be assigned to the CRSO, or designee:

- Overseeing the implementation of the PHDP radiation protection program by Chase Radiation Control Supervisors;
- Reviewing and approving radiation safety procedures to ensure compliance with this DP and the Chase RPP;
- Ensuring compliance with terms and conditions of the Chase radioactive materials license pertaining to the PHDP;
- Developing, maintaining and implementing procedure, recordkeeping and program audits;
- Overseeing the training and qualification program;
- Ensuring personnel assigned to licensed activities are qualified and competent; and
- Serving as a point of contact with the NRC for events such as the loss, theft or damage of radioactive material.

11.2.7 Radiation Control Supervisor (RCS)

The RCS reports directly to the Chase PM for day-to-day supervision and is approved by the CRSO for field implementation of the RPP at the PHDP. If an RCS is not designated for a task, the Chase PM will assume duties of the RCS as approved by the CRSO. The responsibilities of the RCS include but are not limited to the following:

- Monitoring on-site operations to ensure compliance with the RSM;
- Implementing radiological monitoring programs;
- Tracking worker doses;
- Determining appropriate PPE for project personnel;
- Issuing respiratory protection where applicable;

- Ensuring that the CRSO is notified of conditions or situations that present a radiological hazard, concern or exceed limitations set forth in the RSM or applicable procedures and work plans;
- Issuing Radiological Work Permits (RWP) to govern work involving radioactive material; and
- Maintaining records related to the RPP in an auditable condition for the duration of the project.

11.2.8 Radiation Control Technician (RCT)

RCTs report to the RCS and act as the RCS's representatives in specifically implementing the RPP. Responsibilities include but are not limited to the following:

- Performing and documenting radiological surveys;
- Maintaining, inspecting and performing operational checks of field instrumentation;
- Identifying and controlling radiation protection hazards;
- Tracking worker doses;
- Ensuring that the CRSO is notified of conditions or situations that present a radiological hazard, concern or exceed limitations set forth in this RSM or applicable procedures and work plans; and
- Performing job coverage duties, (i.e., surveys, contamination control, air sampling, sample analysis, environmental sampling, custody control, etc.)

11.2.9 Radwaste Manager (RM)

The RM is specifically trained and qualified to package, survey, and ship radioactive materials. The RM reports to the Chase PM and is responsible for implementing the requirements set forth in 10 CFR Part 71, "Packaging and Transportation of Radioactive Material." This person is responsible through direct performance, observation, or receipt of written notification for the following:

- Verifying that the consignee is licensed to receive the shipment of radioactive material and that the material meets the consignee's specific acceptance criteria;
- Preparing and submitting advance notification if required by the receiving facility;
- Obtaining the necessary variances in the event that a shipment does not comply with the consignee's general acceptance criteria;
- Performing various physical tasks necessary to complete the shipment; These tasks include, but are not limited to, the following:
    - Inspecting packages;
    - Marking packages;
    - Labeling packages;
    - Loading and shoring packages;
    - Surveying packages and conveyance;

    - Placarding transport vehicles; and
    - Inspecting transport vehicles.
- Preparing shipping documentation including radiological survey data: the RM will ensure that the materials are properly classified, described and are otherwise appropriate for shipment in accordance with the requirements of 10 CFR Part 71; and
- Verifying that radiation protection equipment used to perform surveys is calibrated, response checked and functioning properly.

11.2.10 Radiation Worker (RW)

Radiation Workers are individuals who have received training for unescorted access into Restricted Areas to perform work where they may receive exposure to ionizing radiation. A Radiation Worker's responsibilities include but are not limited to the following:

- Obeying all posted, verbal, and Radiation Work Permit (RWP) instructions;
- Wearing dosimetry as required;
- Tracking and controlling one's own radiation exposure;
- Minimizing exposure;
- Not eating, drinking or smoking in areas where dispersible radioactive material may be present; and
- Utilizing contamination control techniques to prevent the spread of radioactivity.

11.3 Decommissioning Task Management

Decommissioning activities will be conducted under the provisions of the Chase radioactive materials license and in accordance with this DP. During interim periods with no active remediation, the site will be managed under the MU radioactive materials license. Activities involving licensed material will be conducted in accordance with written and approved procedures, work plans, RWP, and/or FSS survey packages to ensure adequate worker protection and to comply with the radioactive materials license and this DP. Procedures will be reviewed according to the Chase RPP and approved by the MURSO. Work Plans will be developed by the demolition contractor, reviewed by the Chase PM, and approved by the CRSO, MURSO and the MU EHS Director. RWPs and survey package instructions will be approved by the CRSO; alternately, the CRSO may designate an on-site person to approve and initiate RWPs and survey package instructions.

RWPs will be prepared, reviewed and authorized in accordance with the RWP procedure that addresses request, initiation, development, issuance, and termination of an RWP. The RWP contains the location and description of the task to be performed, expected contamination and radiation levels, radiological monitoring requirements, Personal Protective Equipment (PPE) requirements, and special work instructions necessary to complete the work in a safe and compliant manner.

The RCS will initiate the RWP and provide a description on the RWP of existing and/or anticipated radiological conditions. RWP development will include specific identification of the radiological conditions and radiological protection requirements (e.g., clothing, respiratory protection, dosimetry, monitoring, training, etc.). Also, any hold points and special instruction will be described on the RWP. The RWP form contains items such as the job description, location, known radiological conditions, protective clothing requirements, respiratory protection, dosimetry, training, health physics monitoring requirements, and any other special instructions. RWP development also includes creating a sign-in/out sheet for use by the authorized personnel. After development, the RWP must be approved for issuance by the CRSO or designee. Issuance includes a review of the RWP with the authorized users, as required. A pre-job meeting may also be prerequisite to issuance of the RWP.

During use, a copy of the RWP will be maintained at the worksite, and authorized personnel will be required to sign-in/out when participating in the subject activity, indicating their understanding of the requirements of the RWP. RWPs will be terminated upon completion of the activity by signature on the RWP and completion of a form indicating the reason for termination and confirmation of final radiological survey of the activity or area. Upon termination of the RWP, the RWP package will be completed and filed. The package generally contains the completed RWP, sign-in sheets, applicable radiological surveys, and any other documents pertinent to the job. If radiological conditions or requirements change, appropriate changes to the RWP will be made by the CRSO or designee. Alternatively, a new RWP may be issued.

11.4 Project Training Requirements

Chase will provide all project personnel with radiation worker training required by the radioactive materials license, as well as training for project-specific programs, plans, and procedures.

11.4.1 Radiological Training

Radiological training will be completed and documented in accordance with Chase license requirements. The Chase PM will maintain a copy of each individual’s certification on site in the project file.

11.4.2 Project Specific Training

Prior to project start-up, personnel will attend an initial project-specific training session conducted by the Chase PM. The training session will include the following items:

- Review of applicable portions of the DP;
- Discussion regarding the scope of work and planned work activities;

- Review of chemical, physical, and radiological hazards associated with the project;
- Discussion of posting requirements;
- Types and use of available PPE;
- Project security and control of operational work zones;
- Emergency response and site evacuation procedures;
- Project communications;
- General safe work practices;
- Data quality and chain of custody procedures; and
- Review of applicable regulatory standards as applied to project operations.

11.4.3 General Safety Briefings

General safety meetings will be held by the Chase PM at the beginning of each work shift. The purpose of these meetings will be to discuss project status, potential problem areas, general safety concerns, and to reiterate project requirements. Additional meetings will be held if conditions warrant.

11.4.4 Contractor Training

Contractors will be used for asbestos abatement, site preparation, building preparation, and demolition. All contractor personnel will receive training as required by this plan. Contractor personnel who require unescorted access to restricted areas will be trained as Radiation Workers.

11.4.5 Visitor Orientation

All visitors will be briefed on the DP requirements, receive General Orientation training and must be escorted at all times. General Orientation will be administered to all personnel, contractors, and visitors requiring access to restricted areas. The scope of orientation will be commensurate with the activities being performed and the risks involved. The orientation will consist of the following:

- Project-specific health and safety orientation;
- The location of restricted areas;
- Posting and labeling identification of radiological areas and packages;
- Requirement for PPE and dosimetry;
- Escort requirements;
- Review of Regulatory Guide 8.13 “Instructions Concerning Prenatal Radiation Exposure,” Appendix B (required for female contractors or visitors); and

- For visitors, completion of a visitor orientation training completion form.

Escorts will have a minimum of Radiation Worker training. Additionally, all visitors must receive training and/or briefings in accordance with other site policies prior to entering restricted areas of the facility.

11.4.6 Transportation Training

Persons who prepare hazardous materials for transportation or are otherwise responsible for safely transporting hazardous material will be trained in accordance with the requirements of 49 CFR Part 172, Subpart H.

11.5 Contractor Support

MU will utilize Chase for radioactive materials licensing, radiation protection program management and waste management services. Construction/demolition activities will be performed by contractors that are qualified and selected using MU's procurement processes. Radiological work will be performed primarily under the Chase radioactive materials license; however minor tasks may be performed under the MU broad scope radioactive materials license on a case-by-case basis if approved by the Radiation Safety Committee. All work by contractors will be overseen by MU project management and EHS personnel.

12.0 OCCUPATIONAL HEALTH AND SAFETY PROGRAM

Project activities will be conducted utilizing project-specific procedures approved by the MU EHS Director to ensure the proper occupational safety elements are incorporated. Each contractor performing work will conduct the work under their own occupational safety program utilizing plans/procedures approved by MU. Activities of particular importance to this DP are elevated work, confined space entry, energized/active utilities, asbestos abatement, excavation, and demolition.

13.0 RADIATION SAFETY CONTROLS AND MONITORING FOR WORKERS

The RPP will be implemented per the Chase RSM commensurate with the scope and extent of licensed activities at the site. This program and associated operating procedures are the primary means used to administratively establish safe radiation work practices and ensure compliance with NRC requirements. The following sections provide a description of the elements that will be used during implementation of this DP.

13.1 Air Sampling Program

Concentrations of radioactive material in air will be determined by sampling as specified in task-specific RWPs. Air samples will be collected under known physical conditions (e.g., sample time, flow rate). Air sampler flow meters will be calibrated at least annually and following repair and/or modification. The air sampling program will consist of worker breathing zone air samples, general area samples, high volume air samples, and effluent monitoring air samples.

Airborne particulate sampling will be performed during invasive work to assess the potential for internal exposures. Initially, a conservative site-specific modified gross alpha derived air concentration (DAC) will be used to estimate doses from airborne radioactivity. This is conservative because the radionuclide fractions are from the area within Pickard Hall with the highest fraction of Th-232 [6] and the gross alpha result is not corrected for the alphas emitted by progeny. Due to these conservatisms, correction of sample results for dust loading will not be performed.

The site specific Pickard Hall composite DAC (DAC_{PH}) was calculated using the equation below. DAC values are from 10 CFR Part 20 Appendix B, Table 1, Column 3.

$$\frac{1}{\frac{f_{Ra-226}}{DAC_{Ra-226}} + \frac{f_{Th-232}}{DAC_{Th-232}} \frac{f_{U-238}}{x\ DAC_{U-238}}} = DAC_{PH}$$

Where:
DAC_{PH} = Pickard Hall composite DAC (µCi/ml)
f_{Ra-226} = Fraction of Ra-226 in radionuclide distribution
DAC_{Ra-226} = Ra-226 DAC from (µCi/ml)
f_{Th-232} = Fraction of Th-232 in radionuclide distribution
DAC_{Th-232} = Th-232 DAC (µCi/ml)
f_{U-238} = Fraction of U-238 in radionuclide distribution
DAC_{U-238} = U-238 DAC (µCi/ml)

The result of the calculation is shown below.

$$\frac{1}{\frac{0.888}{3E-10\ \mu\text{Ci/ml}} + \frac{0.086}{5E-13\ \mu\text{Ci/ml}} + \frac{0.026}{2E-11\ \mu\text{Ci/ml}}} = 5.7E-12\ \mu\text{Ci/ml}$$

A similar calculation is used to determine the site specific Pickard Hall composite effluent concentration as presented below. Effluent concentrations are from 10 CFR Part 20 Appendix B, Table 2, Column 1.

$$\frac{1}{\frac{0.888}{9E-13\ \mu\text{Ci/ml}} + \frac{0.086}{4E-15\ \mu\text{Ci/ml}} + \frac{0.026}{6E-14\ \mu\text{Ci/ml}}} = 4.4E-14\ \mu\text{Ci/ml}$$

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[6] Soils in the Pickard Hall feeder tunnel have higher concentrations of thorium; because this area is small and isolated, air sampling protocols specific to this area will applied during remediation.

Personnel air sample filters will be collected at the end of each shift. If general area air samplers are run overnight, then the filter media will be collected at the beginning of the next workday. Following air sample filter collection, the filter media will be counted for radioactivity and then stored for decay of short-lived radon progeny before recounting to achieve required sensitivity. If airborne radioactivity levels indicate that assignment of internal dose is required, the CRSO will make the dose assessment based on actual nuclide distribution data. This may be performed using isotopic concentrations of solid samples obtained during remediation or by isotopic analysis of air sample filters from each area. Radon exposures to workers will be monitored as described in section 13.1.5.

The CRSO will apply a graded approach to assigning internal radiological exposures from air sampling. If air sampling indicates that exposures are below 10 percent of the occupational exposure limits utilizing the conservative DAC, then dose assignment is not required. If desired, the CRSO may refine the internal dose assessment by performing radionuclide-specific analysis at an independent radioanalytical laboratory. For further refinement of internal dose assessments, the CRSO can utilize *in vitro* bioassay sampling (urinalysis and/or fecal) to increase the accuracy of internal exposures estimates.

The CRSO will apply professional judgment and experience to identify air sampling appropriate for the specific situation. Such judgment will be based on historical air sampling and survey results, quantity of material being handled, potential for release of contaminants based on physical form and activity, type of confinement or containment, and other factors specific to the activity.

13.1.1 Breathing Zone Air Samples

Breathing zone air samples (belt mounted pump with sample head affixed to worker’s lapel) will be the primary method of monitoring the worker’s intake of radioactive material.

13.1.2 General Area Particulate Air Samples

Air samples will be collected from general and localized areas when and/or where there is potential for generation of airborne radioactive material. These samples will be used to verify that engineering controls are effective and provide warning of elevated concentrations for planning or response actions. In each case, the sampling point will be located in the airflow pathway near the known or suspected release point(s). As necessary, more than one air sample location may be used in order to provide a reasonable estimate of the general concentration of radioactive material in air.

13.1.3 High Volume Air Samples

High volume air sampling may be used to obtain sufficient detection sensitivities for nuclides with low DAC values during short duration activities, or to estimate radon concentrations by measuring the concentrations of particulate progeny.

13.1.4 Effluent Monitoring Air Samples

General area air samples will be collected at effluent release locations around the demolition boundaries as necessary to verify that any radioactive materials released to the environment meet the effluent concentration limits of 10 CFR Part 20, Appendix B, Table 2, Column 1.

13.1.5 Radon Monitoring

Radon levels will be monitored throughout the decommissioning process. Monitors such as the Sun Nuclear Systems Model 1027, or equivalent, will be utilized to provide real-time monitoring of radon levels on a continuous basis. The Sun Nuclear Model 1027 and the 1028 are EPA Evaluated/NEHA-NRPP listed and they are listed on the National Radon Safety Board website under approved devices.

13.2 Respiratory Protection Program

Respiratory protection is not expected to be required for Pickard Hall decommissioning activities. The PHDP respiratory protection program is consolidated into the RSM.

13.3 Internal/External Exposure Determination and Summation

The internal/external dosimetry program is provided in the RSM. Generally, for the PHDP, radiation doses from internal and external sources are expected to be well below 10% of the occupational dose limits, so external and internal dosimetry procedures are not expected to be required. However, Radiation Workers will be monitored for external doses by thermoluminescent dosimeter (TLD) and internal doses by air sampling and/or bioassay. Bioassays are not expected to be performed unless air sampling indicates a potential to exceed 10% of the internal dose limit. The RWP process includes an analysis of the requirements for dosimetry monitoring, air sampling, and respiratory protection.

Results of internal and external monitoring will be used to calculate total organ dose equivalent and total effective dose equivalent to workers for which monitoring is required.

13.4 Contamination and Exposure Control

Personnel exposure to radioactive material will be controlled by application of engineering, administrative, and personnel protection provisions in the order of priority listed below.

13.4.1 Engineering Controls

Engineering controls will be used, as practicable, to minimize or prevent the presence of uncontained radioactive material. Engineering controls will predominantly be comprised of water misting for dust suppression during demolition and containment, isolation, and ventilation during building preparation activities.

All material removal and sampling activities will be conducted in a manner to control the spread of contamination and to maintain personnel exposures ALARA. Containments, HEPA-filtered negative air machines, HEPA-filtered vacuums and water misting for dust suppression will be used as necessary to control airborne particulate radioactivity and fugitive dusts during decommissioning activities.

Engineering controls will also be used to ventilate work areas to control radon levels, if necessary. The procedure will include an evaluation of doses to workers and the public.

13.4.2 Administrative Controls

Administrative controls will be used to control work conditions and work practices and are predominantly comprised of the following:

- *Access Control:* Routine access to work areas will be limited to personnel necessary to accomplish tasks or activities. Access will also be controlled with respect to training and use of specified personal protective equipment.
- *Postings and Barriers:* Postings will be used to inform personnel of relevant hazards or conditions and associated access requirements. Barriers will be used to prevent unauthorized access.
- *Procedures:* Written procedures will be used to describe specific radiation protection requirements necessary for safe performance of tasks.
- *Radiation Work Permits:* RWPs will be used to describe specific or special worker protection requirements for specific activities involving radioactive material

13.4.3 Source Control

Action levels and limits for radiation surveys will be used to control the levels of radioactivity on equipment and in areas. These limits will be designed to maintain exposures to workers ALARA communicated via procedures, RWPs, and/or survey packages.

13.4.4 Personal Protective Equipment

Personal protective equipment will be used to control personnel exposure to radioactive material when administrative controls are not sufficient and engineering controls are not effective or practical. Personal protective equipment will include clothing, gloves, protective shoes or shoe covers, eye protection, and/or respiratory protection as required.

Engineering controls are expected to be sufficient to control airborne radioactivity levels. However, respiratory protection will be used as required for asbestos abatement. Chase and asbestos contractors maintain respiratory protection programs that include medical surveillance, respiratory testing, maintenance, protection factors, workers responsibilities, and respiratory protection limitations.

MU will review these programs and approve them for use prior to use of respiratory protection on-site.

13.5 Notifications

Project personnel will notify the CRSO and MURSO of conditions or situations that present a radiological hazard, concern or exceed limitations set forth in this DP or the Chase RPP. The CRSO or MURSO, as appropriate, will then make notifications to the NRC as required by 10 CFR § 20.2202. Additionally, Section 8.0 requires NRC notification when conditions that are outside the scope of the DP require work to stop.

13.6 Clearance of Materials

Items meeting the limits specified in ANSI/HPS N13.12-2013, "Surface and Volumetric Radioactivity Standards for Clearance" may be released for unrestricted use prior to or during building demolition and soil remediation. These include items of historical significance, furnishings, fixtures, debris from building preparation activities, tools and materials used for project activities, and other items at MU's discretion. This section does not apply to demolition rubble; demolition rubble release methods are described in the Demolition Plan.

The ANSI/HPS N13.12-2013 criteria are listed in Table 1, Group 1 (600 dpm/100 cm^2 average). ANSI/HPS N13.12 does not specify removable surface activity limits, therefore removable alpha surface activity will be limited to 60 dpm α/100 cm^2.

13.7 Audits and Inspection

The CRSO and MURSO are responsible for planned and periodic audits of project activities. These audits will be scheduled in a manner that will provide sufficient coverage and coordination of activities throughout the duration of the project. These audits will verify compliance with the requirements specified in this plan, related procedures, plans, and regulatory requirements. These audit activities also provide a mechanism to identify opportunities for continuous improvement.

In addition to this audit activity, the CRSO/MURSO or designee will perform periodic surveillances to monitor and document compliance with this DP and standard radiological and safety practices.

Surveillances of active decommissioning operations will be conducted at least weekly by the CRSO and MURSO, or designees. Audits by the CRSO and MURSO, or designees, will be performed a minimum of monthly. The specific scheduling of the weekly surveillances and monthly audits will be based on the work status, risk, and complexity of the item or process being performed, such as when new operations are conducted that could have a significant impact on worker doses, public doses, or releases to the environment.

Identified departures from specified requirements will be treated as non-conformances and corrected. Management personnel will take appropriate action to identify root causes, correct deficiencies, prevent recurrences, and determine impacts of audit findings in their area of responsibility. Follow-up actions will be performed as necessary to ensure that appropriate corrective actions have been implemented in a timely manner and are effective.

14.0 ENVIRONMENTAL MONITORING AND CONTROL PROGRAM

By encapsulating all identified removable radioactivity in the building before demolishing the building, the potential for spread of contamination during building demolition is greatly diminished. The use of dust suppression during active demolition will also limit airborne concentrations leaving the site boundaries.

Although the airborne effluent concentrations are expected to be a small fraction of regulatory limits, a rigorous air sampling regimen will be implemented to document the effectiveness of the engineering controls.

The demolition contractor will implement a Stormwater Pollution Prevention Plan (SWPPP) during demolition and excavation. Erosion and sediment control best management practices will be employed to minimize rainwater entering the demolition area. Water will be collected, filtered, analyzed, and treated as necessary to meet the monthly effluent release criteria found in 10 CFR Part 20, Appendix B, Table 3 or disposed as radioactive waste.

The details of the environmental monitoring and control program are described in the Demolition Plan.

15.0 RADIOACTIVE WASTE PROGRAM

Any radioactive waste generated during project activities will be packaged in DOT-compliant containers for shipment. Some waste may require sizing for packaging in the appropriate shipping containers. All radioactive waste will be transported via DOT-approved carriers and manifested by qualified waste shippers and/or brokers to appropriately licensed waste processors and/or disposal sites.

Radioactive waste will be subdivided into categories based on types of material and processing/disposal methods. Solid radioactive subdivisions will include demolition rubble, metals, DAW/combustible, asbestos and soils. Liquid radioactive waste will consist of residual liquids in any drain lines identified, dust suppression water, and water that has infiltrated into the site. No chemicals or reagents will be used that will cause a radioactive waste to become a mixed waste.

Radioactive waste will be disposed at Waste Control Specialists (WCS) in Andrews, Texas or EnergySolutions in Clive, UT. Waste will be adequately characterized to ensure it meets the disposal site's waste acceptance criteria and to complete manifests.

It is possible that unidentified mixed wastes may be identified during demolition or remediation (such as contaminated mercury from drain lines). If unexpected waste is identified, it will be securely contained and labeled, and the NRC will be notified.

Radioactive waste management details are provided in the Demolition Plan and the Remediation and Final Status Survey Plan.

16.0 QUALITY ASSURANCE PROGRAM

The quality assurance (QA) program is developed and organized with emphasis given to maximizing worker safety, eliminating off-site releases, collecting data that meets the data quality objectives (DQO), and minimizing overall project costs. QA criteria are applied in a graded manner to achieve a balance between the rigor of application of quality assurance measures and the scale, cost, and complexity of the work involved.

Accountability for quality is the responsibility of every person assigned to the project, extending from the Chase PM through established lines of authority to all project personnel, who are responsible for the requisite quality of their own work. Quality Assurance will be implemented by personnel conducting their activities to meet requirements and expectations according to established plans and procedures that reflect the way business is to be conducted on the project.

All project personnel are responsible for executing their work and ensuring that quality-affecting activities within their purview are performed in conformance with applicable plans and procedures. All personnel have the authority and responsibility to stop his/her own work and the responsibility to report such conditions when continuation will produce or conceal results that are not in accordance with prescribed requirements, and/or pose imminent radiological or safety hazard to employees, the environment, or the general public. Project personnel have sufficient freedom, authority, access, and responsibility to:

- Identify quality problems, deficiencies, nonconformance's, and noncompliance with regulatory and performance objectives;
- Initiate, recommend, or provide solutions through designated channels;
- Verify implementation of the solutions; and
- Assure that deficient work is stopped or is proceeding under controlled conditions until proper disposition of the unsatisfactory condition is accomplished.

16.1 Nonconformance Control and Corrective Action

All project personnel will be responsible for notifying their supervisor or the Chase PM of conditions or items that do not meet specified requirements. Project procedures address the following measures:

- Identification or segregation of the nonconformance;
- Documentation of the nonconformance;
- Evaluation of the nonconformance;
- Disposition and justification provisions;
- Notification to affected personnel or organizations, and;
- Verification of disposition.

All project personnel are encouraged to identify any activity, process, or procedure that could lead to potential non-conformances or conditions adverse to quality. Corrective Action procedures provide the reporting and evaluation requirements for preventative actions resulting in the elimination of potential quality problems. All non-conformances, corrective actions, and preventative actions will be documented and maintained in accordance with the appropriate procedures.

16.2 Sample Chain-of-Custody

The sample chain-of-custody (COC) maintains the integrity of the sample; that is, there is an accurate record of sample collection, transport, and analysis. This ensures that samples are neither lost nor tampered with, and that the sample analyzed in the laboratory is actually and verifiably the sample taken from a specific location in the field. Samples sent off-site for analysis will use a COC Procedure.

16.3 Survey Documentation

A survey package will be developed for each survey area that provides instructions for the survey and the appropriate forms necessary to document the survey.

16.4 Data Quality Assessment (DQA)

All FSS data will undergo a data quality assessment per the Remediation and Final Status Survey Plan to ensure usability for the intended purpose.

16.5 Quality Assurance Surveys

QA surveys will be conducted by duplicating a minimum of five percent of the FSS measurements to include scans, static measurements, smears, and soil samples. The contract laboratory will implement their internal QA procedures related to sample analysis.

17.0 PROJECT RADIATION SURVEYS

17.1 In-Process Surveys

Decommissioning activities will be conducted to control the spread of contamination and keep personnel exposures ALARA. In-process surveys will be conducted in support of project activities to monitor the effectiveness of contamination controls and engineering controls, and to ensure that surrounding areas are not cross-contaminated. In-process survey protocols are discussed in task-specific plans.

Radiological surveys will be performed to describe the radiation types and levels in an area or during a task, to identify or quantify radioactive material, and to evaluate potential and known radiological hazards. In-process surveys will consist of dose rate surveys, airborne radioactivity monitoring, scan surveys, static measurements, removable contamination measurements, and solid samples. Additionally, personnel will be surveyed prior to leaving access-controlled areas.

17.2 Characterization Surveys

Characterization surveys will be completed according to the Characterization Plan.

17.3 Final Status Surveys

FSS will begin after completion of site remediation (remediation of soils and adjoining structures/systems remaining after building demolition). FSS will be performed using the DQO process to ensure data are of a sufficient quality to be useful for intended purposes. FSS for soils will consist of surface scans for gamma emissions and soil sampling at discrete locations. FSS for remaining structures will consist of gamma scans, alpha/beta scans and static measurements, and alpha removable activity measurements.

Final Status surveys will be completed according to the Remediation and FSS Plan.

17.4 Survey Instrumentation

Radiation detection instruments will be selected to meet the DQOs for their intended purpose.

17.4.1 Instrumentation Specifications

The instrumentation to be used on the PHDP are presented in the table below. As long as DQOs are met, alternate or additional instrumentation with similar detection capabilities may be utilized as needed for survey requirements with CRSO approval.

Table 17-1: Instrumentation Specifications

Detector Model	Detector Type	Detector Width	Detector Area	Meter Model	Window Thickness	Use
Ludlum 43-68	Gas Flow Proportional	8.8 cm	126 cm^2	Ludlum 2221	0.8 mg/cm^2	Total Surface Activity
Ludlum 43-37	Gas Flow Proportional	13.3 cm	584 cm^2	Ludlum 2221	0.8 mg/cm^2	Total Surface Activity
Ludlum 43-10-1	Phoswich	N/A	N/A	Ludlum 2929	0.4 mg/cm^2	Removable / Airborne Activity
Ludlum 44-10	2" x 2" Sodium Iodide	N/A	N/A	Ludlum 2241	N/A	Gamma Scans
Bicron MicroRem	Tissue Equivalent Organic Scintillation	N/A	N/A	N/A	N/A	Dose Rate Measurements

17.4.2 Instrument Calibration

Laboratory and portable field instruments will be calibrated at least annually with National Institute of Standards and Technology (NIST) traceable sources, where feasible, and to radiation emission types and energies that will provide detection capabilities similar to the nuclides of concern.

17.4.3 Functional Checks

Functional checks will be performed at least daily when in use to ensure that the instrument is in proper working condition. The background, source check, and field measurement count times for radiation detection instrumentation will be specified by procedure to ensure measurements are statistically valid. Background measurements will be taken as part of the daily instrument check and compared with the acceptance range for instrument and site conditions. An instrument will be removed from service if the source check is not within ±20 percent of the initial post-calibration value. If an instrument fails a functional check, it will be removed from service and all data obtained with the instrument since the last satisfactory check will be evaluated for usability and unusable data discarded.

17.4.4 Surface Activity Efficiency Determination

Detector efficiencies for quantifying residual surface activity are based on beta emissions. Beta emissions may provide more representative results when surface conditions are highly variable and result in greater uncertainty in quantifying the alpha emission component. The efficiencies are in terms of the cpm of the entire decay chain per dpm of the parent nuclide; Ra-226 for Ra-226+C chain, Th-232 for the Th-232+C chain, and U-238 for the tailings chain.

Characterization measurements of total alpha + beta and alpha-only measurements indicate self-shielding of alpha emissions on most surfaces. For conservatism, only the beta emissions will be considered in determining the detector efficiency for alpha + beta total surface activity measurements. Due to this conservatism, there is no need to analyze the effects of equilibrium state, radon emanation, or self-shielding of betas.

Total detection efficiencies for gas flow detectors are determined based on the combined contribution of all beta emitters in the decay chains including surface efficiency and radon emanation considerations.[7] These efficiencies are conservative because:

- Any contribution form alpha emissions are not included
- Conservative beta efficiencies are applied to each nuclide
- ISO 7503-1 surface efficiencies are considered conservative for most surfaces
- Not all emissions are considered in determining the efficiencies; therefore the actual efficiencies are underestimated.

The calculations used to determine the detection efficiencies are provided in the tables below. Th-230 is included in the event it is identified in disequilibrium with U-238 on structural surfaces during characterization; in that case, the nuclide fractions can be updated to determine an appropriate weighted efficiency.

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[7] The gas flow detectors will be operated in the "beta" channel that measures alpha emissions in addition to beta emissions.

Table 17-2: Gas Flow Detector Ra-226+C Efficiency Calculations

Nuclide	Fraction of Parent Activity	Emission (β E_{AVE}) [8]	Yield	2-pi E_i	E_s	Emanation Factor [9]	Weighted Efficiency [10]
Ra-226	1.00	Alpha	1	0.43	0.25	1	---
Rn-222	1.00	Alpha	1	0.48	0.25	0.8	---
Po-218	1.00	Alpha	1	0.48	0.25	0.8	---
Pb-214	1.00	Beta (0.225)	1	0.51	0.5	0.8	0.204
Bi-214	1.00	Beta (0.639)	1	0.54	0.5	0.8	0.216
Po-214	1.00	Alpha	1	0.48	0.25	0.8	---
Pb-210	1.00	Beta (0.006)	1	0	0.25	0.8	0.000
Bi-210	1.00	Beta (0.389)	1	0.53	0.5	0.8	0.212
Po-210	1.00	Alpha	1	0.48	0.25	0.8	---
Total	**9.00**					**Total Eff.**	**0.632**

Table 17-3: Gas Flow Detector Th-230 Efficiency Calculations

Nuclide	Fraction of Parent Activity	Emission (β E_{AVE}) [8]	Yield	2-pi E_i	E_s	Emanation Factor [9]	Weighted Efficiency [10]
Th-230	1.00	Alpha	1	0.41	0.25	1	---
Total	**1.00**					**Total Eff.**	**0**

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[8] Total beta energies from Appendix A of NUREG 1507, Tables A-24, A-31, and A-37.

[9] The emanation factor is based on the RESRAD-BUILD default radon emanation fraction of 0.2.

[10] The calculated efficiency is in units of cpm per dpm of the parent nuclide (Ra-226, Th-232, or U-238). The gas flow detector total efficiency for each emission is calculated by multiplying the fraction of parent activity, yield, 2-pi instrument efficiency, surface efficiency, and emanation fraction. The fractional efficiency for each emission is summed to determine the total efficiency.

Table 17-4: Gas Flow Detector Th-232+C Efficiency Calculations

Nuclide	Fraction of Parent Activity	Emission (β E$_{AVE}$) [8]	Yield	2-pi E$_i$	E$_s$	Emanation Factor [9]	Weighted Efficiency [10]
Th-232	1.00	Alpha	1	0.26	0.25	1	---
Ra-228	1.00	Beta (0.007)	1	0	0.25	1	0.000
Ac-228	1.00	Beta (0.349)	0.93	0.53	0.5	1	0.246
Th-228	1.00	Alpha	1	0.48	0.25	1	---
Ra-224	1.00	Alpha	0.95	0.48	0.25	1	---
Rn-220	1.00	Alpha	1	0.48	0.25	0.8	---
Po-216	1.00	Alpha	1	0.48	0.25	0.8	---
Pb-212	1.00	Beta (0.100)	1	0.44	0.25	0.8	0.088
Bi-212	0.64	Beta (0.771)	1	0.54	0.5	0.8	0.138
Bi-212	0.36	Alpha	1	0.48	0.25	0.8	---
Po-212	0.64	Alpha	1	0.48	0.25	0.8	---
Tl-208	0.36	Beta (0.559)	1	0.54	0.5	0.8	0.078
Total	**10.00**					**Total Eff.**	**0.550**

Table 17-5: Gas Flow Detector Tailings Efficiency Calculations [11]

Nuclide	Fraction of Parent Activity	Emission (β E$_{AVE}$) [8]	Yield	2-pi E$_i$	E$_s$	Emanation Factor [9]	Weighted Efficiency [10]
U-238	1.00	Alpha	1	0.31	0.25	1	---
Th-234	1.00	Beta (0.0478)	1	0.33	0.25	1	0.083
Pa-234	1.00	Beta (0.809)	1	0.54	0.5	1	0.270
U-234	1.02	Alpha	1	0.43	0.25	1	---
Th-230	1.02	Alpha	1	0.41	0.25	1	---
U-235	0.048	Alpha	1	0.37	0.25	1	---
Th-231	0.048	Beta (0.078)	1	0.42	0.25	1	0.005
Total	**5.14**					**Total Eff.**	**0.358**

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[11] U-235 progeny below Th-231 not included due to low contribution to total efficiency.

The weighted total efficiency for the mixture of radionuclides is calculated in the table below. The weighted efficiency can be corrected for differing fractions if characterization surveys identify differing mixtures.

Table 17-6: Gas Flow Detector Weighted Efficiency

Nuclide	Fraction	Efficiency	Total
Ra-226	0.888	0.632	0.561
Th-230	0.000	0.000	0.000
Th-232	0.086	0.550	0.049
U-238	0.026	0.358	0.009
		Total Eff.	**0.619**

Removable activity measurements (disc smears) will be counted in the Ludlum 2929 alpha-beta counter. Alpha results will be used to demonstrate compliance with the removable activity DCGL. Because smear measurements are not influenced by the surface conditions in the field, the 4-pi efficiency is used. Final status smears are expected to be from relatively clean surfaces such that a correction factor for self-shielding is not used. The calculation of the detector efficiency is presented in the table below.

Table 17-7: Smear Counter Ra-226+C Efficiency Calculations

Nuclide	Fraction of Parent Activity	Emission	Yield	4-pi E_i	Emanation Factor [9]	Weighted Efficiency [12]
Ra-226	1.00	Alpha	1	0.32	1	0.320
Rn-222	1.00	Alpha	1	0.32	0.8	0.256
Po-218	1.00	Alpha	1	0.32	0.8	0.256
Po-214	1.00	Alpha	1	0.32	0.8	0.256
Po-210	1.00	Alpha	1	0.32	0.8	0.256
Total	**5.00**				**Total Eff.**	**1.344**

Table 17-8: Smear Counter Th-230 Efficiency Calculations

Nuclide	Fraction of Parent Activity	Emission	Yield	4-pi E_i	Emanation Factor [9]	Weighted Efficiency [12]
Th-230	1.00	Alpha	1	0.32	1	0.326
Total	**1.00**				**Total Eff.**	**0.326**

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[12] The calculated efficiency is in units of cpm per dpm of the parent. The efficiency for each emission is calculated by multiplying the fraction of parent activity, yield, 4-pi instrument efficiency, and emanation fraction. The fractional efficiency for each emission is summed to determine the total efficiency.

Table 17-9: Smear Counter Th-232+C Efficiency Calculations

Nuclide	Fraction of Parent Activity	Emission	Yield	4-pi E_i	Emanation Factor [9]	Weighted Efficiency [12]
Th-232	1.00	Alpha	1	0.32	1	0.320
Th-228	1.00	Alpha	1	0.32	1	0.320
Ra-224	1.00	Alpha	1	0.32	1	0.320
Rn-220	1.00	Alpha	1	0.32	0.8	0.256
Po-216	1.00	Alpha	1	0.32	0.8	0.256
Bi-212	0.36	Alpha	1	0.32	0.8	0.092
Po-212	0.64	Alpha	1	0.32	0.8	0.164
Total	**6.00**				**Total Eff.**	**1.728**

Table 17-10: Smear Counter Tailings Efficiency Calculations [11]

Nuclide	Fraction of Parent Activity	Emission	Yield	4-pi E_i	Emanation Factor [9]	Weighted Efficiency [12]
U-238	1.00	Alpha	1	0.32	1	0.320
U-234	1.02	Alpha	1	0.32	1	0.326
Th-230	1.02	Alpha	1	0.32	1	0.326
U-235	0.048	Alpha	1	0.32	1	0.015
Total	**9.00**				**Total Eff.**	**0.988**

The weighted total efficiency for the mixture of radionuclides is calculated in the table below. The weighted efficiency can be corrected for differing fractions if characterization surveys identify differing mixtures.

Table 17-11: Smear Counter Weighted Efficiency

Nuclide	Fraction	Efficiency	Total
Ra-226	0.888	1.344	1.193
Th-230	0.000	0.326	0.000
Th-232	0.086	1.728	0.149
U-238	0.026	0.988	0.026
		Total Eff.	**1.368**

17.4.5 Minimum Detectable Concentrations

Minimum counting times and scanning rates for radioactivity measurements will be chosen to provide detection sensitivities sufficient for the intended use of the data. Count times and scanning rates are determined using the following equations:

17.4.5.1 Alpha+Beta Surface Activity (Static Counting)

Static counting MDC at a 95% confidence level is calculated using the following equation, which is an expansion of NUREG-1507, "Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions," Table 3.1 (Strom & Stansbury, 1992):

$$MDC_{static} = \frac{3 + 3.29\sqrt{B_r \cdot t_s \cdot (1 + \frac{t_s}{t_b})}}{t_s \cdot E_{tot} \cdot \frac{A}{100cm^2}}$$

Where:

MDC_{static} = minimum detectable concentration (dpm/100 cm^2)
B_r = background count rate (cpm)
t_b = background count time (min)
t_s = sample count time (min)
E_{tot} = total detector efficiency for radionuclide emission of interest (cpm/dpm)
A = detector probe area (cm^2)

An example calculation for a 43-68 detector is provided below.

$$\mathrm{MDC_{static}} = \frac{3+3.29\sqrt{(500)(0.1)\left(1+\frac{0.1}{0.1}\right)}}{(0.1)(0.619)\left(\frac{126}{100\ \mathrm{cm}^2}\right)} = 520\ \mathrm{dpm/100\ cm^2}$$

17.4.5.2 Alpha+Beta Surface Activity Ratemeter Scanning

Scanning MDC is calculated using the following equation, which is a combination of MARSSIM equations 6-8, 6-9, and 6-10:

$$MDC_{scan} = \frac{d'\sqrt{b_i}\left(\frac{60}{i}\right)}{\sqrt{p} \cdot E_{tot} \cdot \frac{A}{100cm^2}}$$

Where:

MDC_{scan} = minimum detectable concentration level (dpm/100 cm^2)
d' = desired performance variable (1.38)
b_i = background counts during the residence interval
i = residence interval (sec)
p = surveyor efficiency (0.5)
E_{tot} = total detector efficiency for radionuclide emission of interest (includes combination of instrument efficiency and surface efficiency) (cpm/dpm)
A = detector probe area (cm^2)

An example calculation for a 43-37 detector is provided below.

$$\text{i} = 13.3\text{ cm} \cdot \frac{\text{inch}}{2.54\text{ cm}} \cdot \frac{\text{sec}}{20\text{ inch}} = 0.262\text{ sec}$$

$$\text{b}_\text{i} = 0.262\text{ sec} \cdot \frac{1500\text{ counts}}{\text{minute}} \cdot \frac{\text{minute}}{60\text{ sec}} = 6.55\text{ counts}$$

$$MDC_{scan} = \frac{1.38\sqrt{6.55}\left(\frac{60}{0.262}\right)}{\left(\sqrt{0.5}\right)(0.619)\left(\frac{584}{100\ cm^2}\right)} = 316\ dpm/100\ cm^2$$

17.4.5.3 Removable Surface Activity

Removable surface activity (smear) counting MDC at a 95% confidence level is calculated using the following equation, which is NUREG-1507, Table 3.1 (Strom & Stansbury, 1992):

$$MDC_{smear} = \frac{3 + 3.29\sqrt{B_r \cdot t_s \cdot (1 + \frac{t_s}{t_b})}}{t_s \cdot E}$$

Where:

MDC_{smear} = minimum detectable concentration level (dpm/smear)
B_r = background count rate (cpm)
t_b = background count time (min)
t_s = sample count time (min)
E = instrument efficiency for radionuclide emission of interest (cpm/dpm)

An example calculation for the 43-10-1 detector alpha channel is provided below.

$$MDC_{smear,alpha} = \frac{3 + 3.29\sqrt{(1)(1)\left(1 + \frac{1}{1}\right)}}{(1)(1.37)} = 6\ dpm/100\ cm^2$$

17.4.5.4 Volumetric Gamma Scanning

The scan MDC for soils is determined using the methodology presented in Section 6.2.5 of NUREG-1507. This correlation requires four steps. First, establishing an $MDCR_{surveyor}$ count rate for the anticipated background; second, determining the relationship between the radionuclide contamination and count rate per exposure rate (cpm per µR/hr) using MicroShield^{TM} software; third, determining the ratio of the $MDCR_{surveyor}$ to the nuclide specific count rate per exposure rate (cpm per µR/hr); and finally, the correlating the minimum exposure rate to an activity.

Determine $MDCR_{surveyor}$

The number of source counts required for a specific time interval is given by MARSSIM Equation 6-8:

$$s_i = d'\sqrt{b_i}$$

where:
d' is the performance factor based on required true and false positives rates (1.38), and
b_i is the number of background counts in the observation interval

Assuming that the source remains under the detector for 2 seconds (e.g. *i*=2) and the background count rate is 10,000 cpm. The value for b_i and s_i is then calculated:

$$b_i = \frac{10{,}000}{60} \times 2 = 333 \text{ counts/interval}$$

$$s_i = 1.38 \times \sqrt{333} = 25.2$$

The scan minimum detectable count rate is then calculated using the following MARSSIM equation 6-9:

$$MDCR = s_i \times (60/i)$$

where:
MDCR is the Minimum Detectable Count Rate

$$MDCR = 25.2 \times (60/2) = 756$$

The $MDCR_{surveyor}$ is calculated assuming a surveyor efficiency of 0.5 using MARSSIM equation 6-10:

$$MDCR_{surveyor} = \frac{MDCR}{\sqrt{0.5}} \text{ cpm}$$

$$MDCR_{surveyor} = \frac{756}{\sqrt{0.5}} = 1,069\ \text{cpm}$$

Radionuclide (cpm per μR/hr)

For the corresponding minimum detectable exposure rate to be determined for the detector and radioactive material decay series, it is necessary to run MicroShield™ and determine the count rate to exposure rate ratio (cpm per μR/hr) considering each of the gamma emissions and their contribution to the total exposure rate for the nuclide and progeny.

MicroShield™ was used to determine the net exposure rate produced by an arbitrary total concentration of 1pCi/g in soil for each nuclide decay chain. The following factors were considered in the modeling:

- 1 pCi/g of parent nuclide (entered as 1.65E-6 μCi/cm^3)
- Dimensions of hot spot: radius equal to 28 cm
- Depth of hot spot: 15 cm
- Location of dose point: Centered 10 cm above the source, as this position is consistent with the maximum height of the NaI scintillation detector above the ground during scanning
- Density of soil: 1.65 g/cm^3

The modeling code performed the calculations and determined a total exposure rate with buildup of 0.72 μR/hr for Ra-226, 2.38E-4 μR/hr for Th-230, 1.01 μR/hr for Th-232, and 1.93E-2 μR/hr for U Tailings. The output reports are presented in Appendix E. MicroShield™ also provided the exposure rates for a number of gamma energies associated with the source term inputs. This data was used to weight the cpm per μR/hr value at each energy by the fractional exposure rate to estimate an overall cpm per μR/hr value specific to the source term as presented in the tables below. The results of these calculations were 837 cpm per μR/hr for Ra-226, 3,770 cpm per μR/hr for Th-230, 838 cpm per μR/hr for Th-232, and 3,530 cpm per μR/hr for U Tailings.

Table 17-12: Ra-226+C NaI Detector Response (cpm per μR/hr)

Energy (MeV)	Detector Response (cpm per μR/hr)[13]	Exposure Rate (μR/hr)	Weighted Response (cpm per μR/hr)[14]
0.015	1,160	7.58E-04	1.22E+00
0.05	11,300	3.67E-04	5.75E+00
0.08	12,000	4.07E-03	6.77E+01
0.1	9,970	3.67E-05	5.08E-01
0.2	4,320	8.62E-03	5.17E+01
0.3	2,540	2.71E-02	9.55E+01
0.4	1,710	6.87E-02	1.63E+02
0.5	1,270	4.03E-03	7.11E+00
0.6	1,010	1.30E-01	1.82E+02
0.8	710	3.30E-02	3.25E+01
1	550	1.33E-01	1.02E+02
1.5	350	1.13E-01	5.48E+01
2	270	1.98E-01	7.42E+01
Totals		**7.21E-01**	**8.37E+02**

Table 17-13: Th-230 NaI Detector Response (cpm per μR/hr)

Energy (MeV)	Detector Response (cpm per μR/hr)[13]	Exposure Rate μR/hr	Weighted Response (cpm per μR/hr)[14]
0.015	1,160	1.63E-04	7.97E+02
0.06	12,700	3.77E-05	2.02E+03
0.15	6,190	3.67E-05	9.57E+02
Totals		**2.38E-04**	**3.77E+03**

---

[13] Values for energies presented are from NUREG-1507 Table 6-3.

[14] The weighted response is equal to the exposure rate associated with the gamma energy of interest (μR/hr) divided by the total exposure rate for all gamma energies (μR/hr) multiplied by the detector response for the gamma energy of interest (cpm per μR/hr).

Table 17-14: Th-232+C NaI Detector Response (cpm per μR/hr)

Energy (MeV)	Detector Response (cpm per μR/hr)[13]	Exposure Rate μR/hr	Weighted Response (cpm per μR/hr)[14]
0.015	1,160	1.58E-03	1.81E+00
0.04	8,480	5.30E-05	4.44E-01
0.06	12,700	7.00E-05	8.78E-01
0.08	12,000	7.61E-03	9.03E+01
0.1	9,970	1.92E-03	1.89E+01
0.15	6,190	2.24E-03	1.37E+01
0.2	4,320	4.35E-02	1.86E+02
0.3	2,540	3.42E-02	8.59E+01
0.4	1,710	4.25E-03	7.17E+00
0.5	1,270	3.14E-02	3.94E+01
0.6	1,010	8.55E-02	8.54E+01
0.8	710	1.11E-01	7.82E+01
1	550	2.48E-01	1.35E+02
1.5	350	7.95E-02	2.75E+01
2	270	2.25E-03	6.00E-01
3	190	3.58E-01	6.72E+01
Totals		**1.01E+00**	**8.38E+02**

Table 17-15: U Tailings NaI Detector Response (cpm per μR/hr)

Energy (MeV)	Detector Response (cpm per μR/hr)[13]	Exposure Rate μR/hr	Weighted Response (cpm per μR/hr)[14]
0.015	1,160	9.39E-04	5.64E+01
0.02	2,150	6.67E-07	7.43E-02
0.03	5,030	4.30E-05	1.12E+01
0.04	8,480	9.43E-07	4.14E-01
0.05	11,300	3.86E-05	2.26E+01
0.06	12,700	4.37E-04	2.88E+02
0.08	12,000	5.55E-04	3.45E+02
0.1	9,970	2.01E-03	1.04E+03
0.15	6,190	7.23E-04	2.32E+02
0.2	4,320	2.98E-03	6.66E+02
0.3	2,540	3.80E-03	5.00E+02
0.4	1,710	2.23E-03	1.97E+02
0.5	1,270	5.15E-05	3.39E+00
0.8	710	1.40E-03	5.13E+01
1	550	4.10E-03	1.17E+02
Totals		**1.93E-02**	**3.53E+03**

Minimum Detectable Exposure Rate

The minimum detectable exposure rate is calculated by dividing the $\text{MDCR}_{\text{surveyor}}$ count rate (1,069 cpm) by the count rate-to-exposure rate ratio for the detector as shown below.

$$\text{Minimum Detectable Exposure Rate (Ra-226)} = \frac{\text{1,069 cpm}}{\text{837 cpm µR/hr}} = 1.28\ \mu R/hr$$

$$\text{Minimum Detectable Exposure Rate (Th-230)} = \frac{\text{1,069 cpm}}{\text{3,770 cpm µR/hr}} = 0.28\ \mu R/hr$$

$$\text{Minimum Detectable Exposure Rate (Th-232)} = \frac{\text{1,069 cpm}}{\text{838 cpm µR/hr}} = 1.28\ \mu R/hr$$

$$\text{Minimum Detectable Exposure Rate (U Tailings)} = \frac{\text{1,069 cpm}}{\text{3,530 cpm µR/hr}} = 0.30\ \mu R/hr$$

Scan MDC (pCi/g)

The scan MDC can be derived by the ratios of the minimum detectable exposure rate to the calculated exposure rate provide by the MicroShield™ modeling previously described.

$$\text{Scan MDC (Ra-226)} = 1\frac{pCi}{g} * \frac{1.28\ {}^{\mu R}/_{hr}}{0.72\ {}^{\mu R}/_{hr}} = 1.8\ \frac{pCi}{g}\ \text{Ra-226}$$

$$\text{Scan MDC (Th-230)} = 1\frac{pCi}{g} * \frac{0.28\ {}^{\mu R}/_{hr}}{0.000238\ {}^{\mu R}/_{hr}} = 1{,}191\ \frac{pCi}{g}\ \text{Th-230}$$

$$\text{Scan MDC (Th-232)} = 1\frac{pCi}{g} * \frac{1.28\ {}^{\mu R}/_{hr}}{1.01\ {}^{\mu R}/_{hr}} = 1.3\ \frac{pCi}{g}\ \text{Th-232}$$

$$\text{Scan MDC (U Tailings)} = 1\frac{pCi}{g} * \frac{0.3\ {}^{\mu R}/_{hr}}{0.0193\ {}^{\mu R}/_{hr}} = 15.7\ \frac{pCi}{g}\ \text{U Tailings}$$

17.4.5.5 Airborne Particulate Samples

Air sampling MDC is calculated using the following equation:

$$MDC = \frac{3 + 3.29 * \sqrt{B_r * t_s * (1 + {}^{t_s}/_{t_b})}}{2.22E6 * E * \ t_s * \ F * \ t_a}$$

Where:
Br = background count rate (counts per minute)
t_s = sample count time (minutes)
t_b = background count time (minutes)
t_a = air sampler collection time (minutes)
F = air sampler flow rate (milliliters per minute)
E = detector efficiency

An example calculation for area air sampling using 10-minute count times for both background and sample, and a 2 cfm air sampler running for 8 hours is presented below.

$$MDC_{alpha} = \frac{3 + 3.29 * \sqrt{1 * 10 * (1 + {}^{10}/_{10})}}{2.22E6 * 0.32 * \ 10 * \ 5.66E4 * \ 4.80E2} = 9.2\text{E} - 14\ \mu\text{Ci/ml}$$

An example calculation for breathing zone air sampling using 60-minute count times for both background and sample, and a 3 lpm air sampler running for 8 hours is presented below.

$$MDC_{alpha} = \frac{3 + 3.29 * \sqrt{1 * 60 * (1 + {}^{60}/_{60})}}{2.22E6 * 0.32 * \ 60 * \ 3.00E3 * \ 1.00E4} = 6.4\text{E} - 13\ \mu\text{Ci/ml}$$

An example calculation for effluent air sampling using 60-minute count times for both background and sample, and a 2 cfm air sampler running for 7 days is presented below.

$$MDC_{alpha} = \frac{3 + 3.29 * \sqrt{1 * 60 * (1 + {}^{60}/_{60})}}{2.22E6 * 0.32 * \ 60 * \ 5.66E4 * \ 1.00E4} = 1.6\text{E} - 15\ \mu\text{Ci/ml}$$

18.0 REPORTS

At the completion of characterization and final status surveys, Chase will develop a report of task activities and present radiological data. The report will provide a description of task activities, radiological survey results, and calculations of potential future doses to the public. The guidance contained in NUREG-1757 will be used to determine the appropriate content of the characterization and final status survey reports. The reports will be reviewed for technical content by Chase personnel and will be submitted to MU for review and approval, then submitted to the NRC.

19.0 FINANCIAL ASSURANCE

19.1 PHDP Cost Estimate

The decommissioning cost estimate is summarized in the table below. It is estimated that approximately $12 million is required for the PHDP. The cost estimate includes the demolition contractor costs, subcontractor costs, and other direct costs. The estimate includes the costs of shipping and disposing of waste and the FSS. A contingency of 25% is included in the decommissioning costs to ensure that sufficient funds are available to cover costs that may result from unanticipated conditions or unforeseeable elements in the project scope. Typically, these include factors such as waste disposal rates or increased waste volumes from undiscovered or uncharacterized areas. In addition, the time duration between the development of the DP and the inception of decommissioning activities can influence the costs associated with changes in the economy and changes in regulatory requirements. This cost estimate was completed in 2021 based on an assumption that the entire building will be disposed as radioactive waste. The current plan is to dispose of a majority of the building as clean demolition debris at a local landfill. The cost savings associated with local landfill disposal more than offsets any increases in the costs of goods and services since the estimate was completed. After a demolition contractor is procured, the cost estimate will be updated.

Table 19-1: Decommissioning Cost Estimate

WBS No.	Description	TOTAL
1	Project Planning	$100,000
2	Facility Preparation	$200,000
3	Mobilization and Training	$55,000
4	Building Demolition and Soil Remediation	$2,300,000
5	Waste Transportation and Disposal	$6,450,000
6	Final Status Survey and Report	$75,000
7	Backfill and Site Restoration	$160,000
	SUBTOTAL	**$9,340,000**
	Contingency @ 25%	$2,335,000
	TOTAL DECOMMISSIONING COST	**$11,675,000**

19.2 Certification Statement and Financial Mechanism

As part of the MU broad scope license Decommissioning Funding Plan, and consistent with 10 CFR § 30.35(f)(4) and 10 CFR § 40.36(e)(4) (because MU is a state-owned entity), MU provided the NRC with a certification of financial assurance and Statement of Intent on February 5, 2021 indicating that funds are available for the decommissioning of licensed facilities. The associated decommissioning cost estimate for the license was $18,221,046 with $15,767,325 allocated to decommissioning Pickard Hall and Schweitzer Hall.

20.0 REFERENCES

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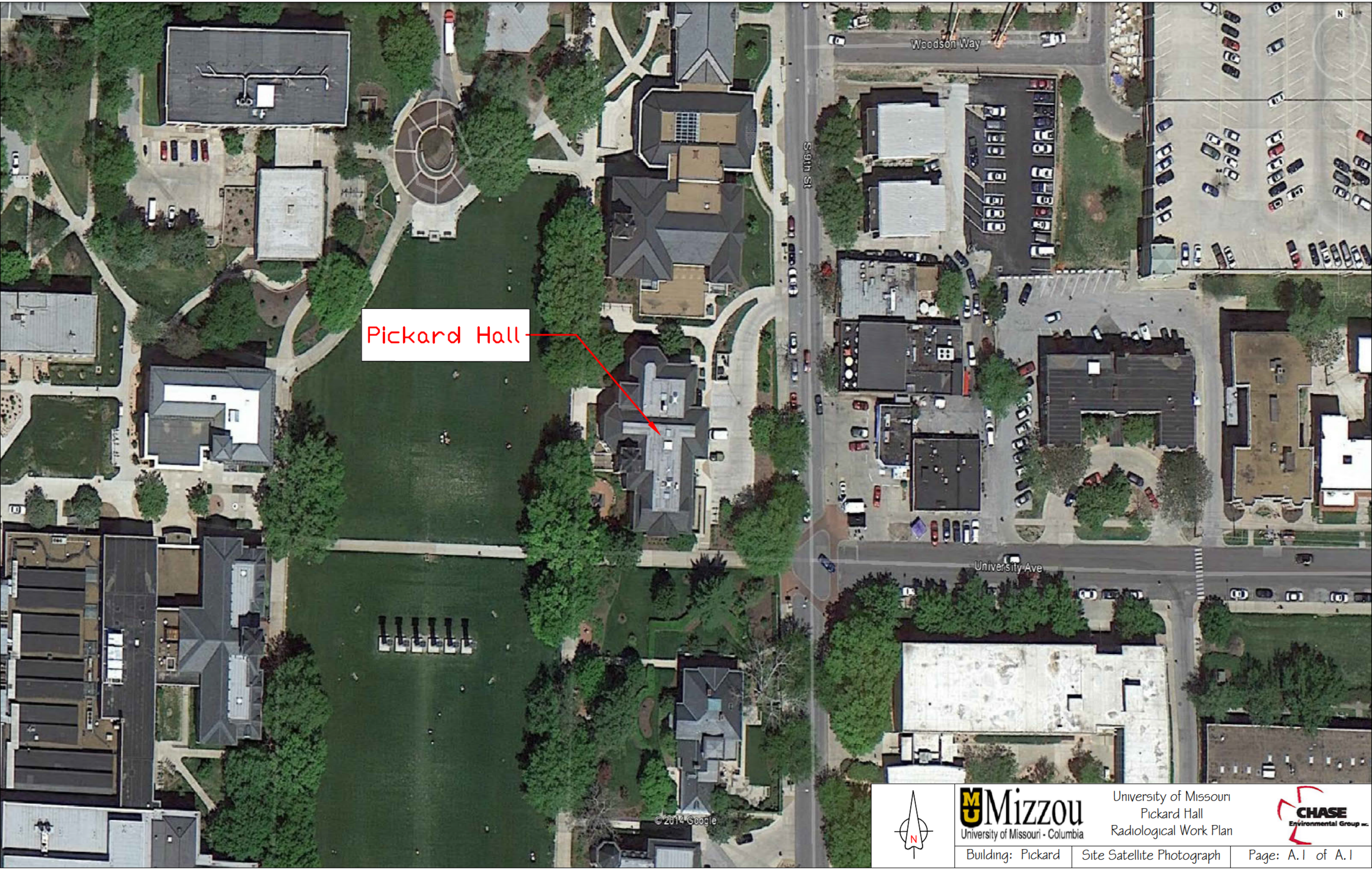
32. "University of Missouri Pickard Hall Pre-Decommissioning Characterization Report", December 11, 2020
33. "University of Missouri Pickard Hall Tunnel Subsurface Soil Sampling Report," March 4, 2022
34. "2019 Annual Drinking Water Quality Report," University of Missouri Public Water System
35. "University Of Missouri Decommissioning Funding Plan," February 5, 2021

Appendix A
Site Satellite Photo



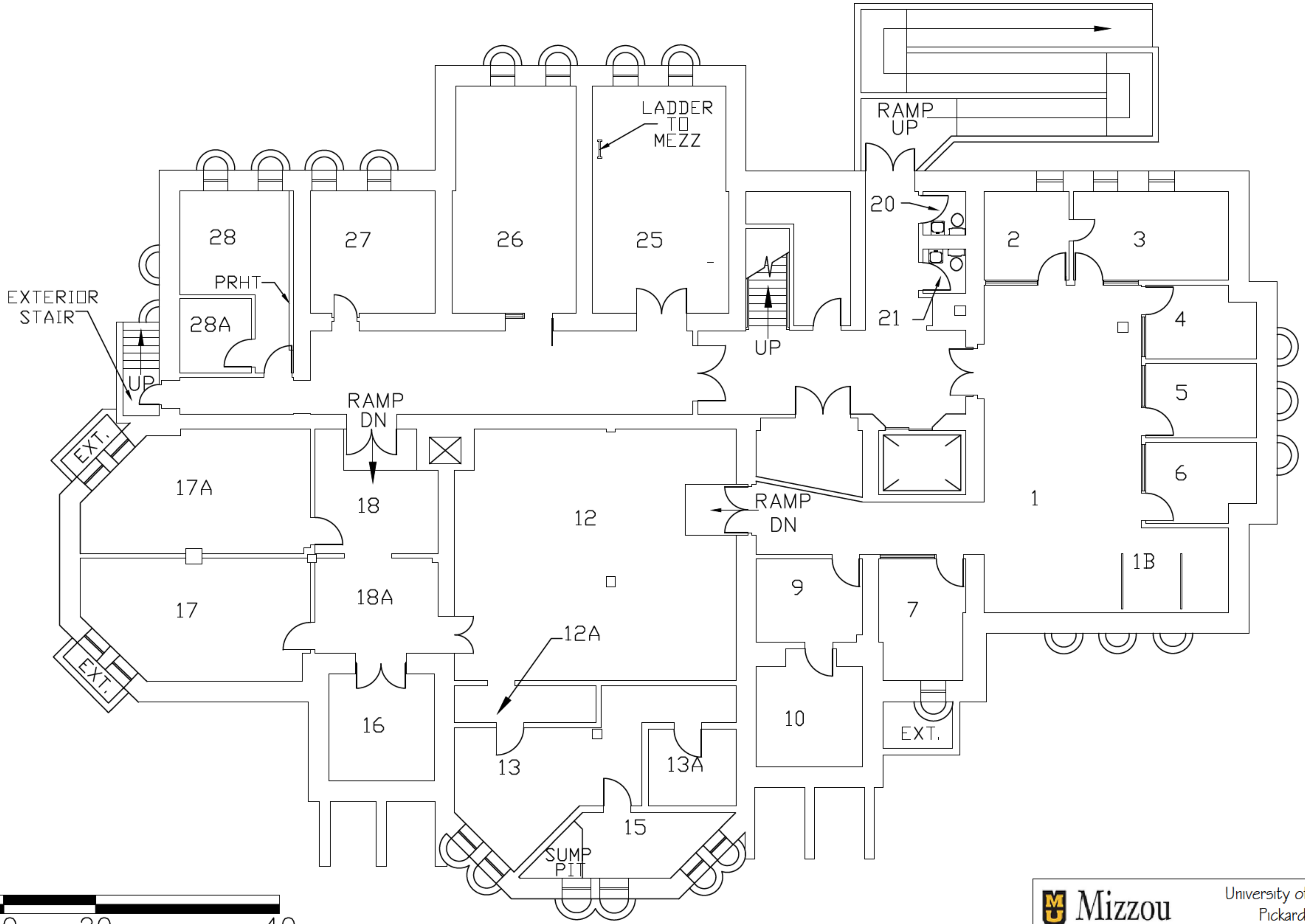
MU Mizzou
University of Missouri - Columbia

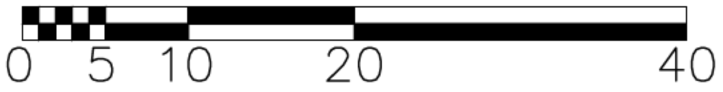
University of Missouri
Pickard Hall
Radiological Work Plan

CHASE Environmental Group inc.

Building: Pickard	Site Satellite Photograph	Page: A.1 of A.1

Appendix B
Current Building Floor Plans



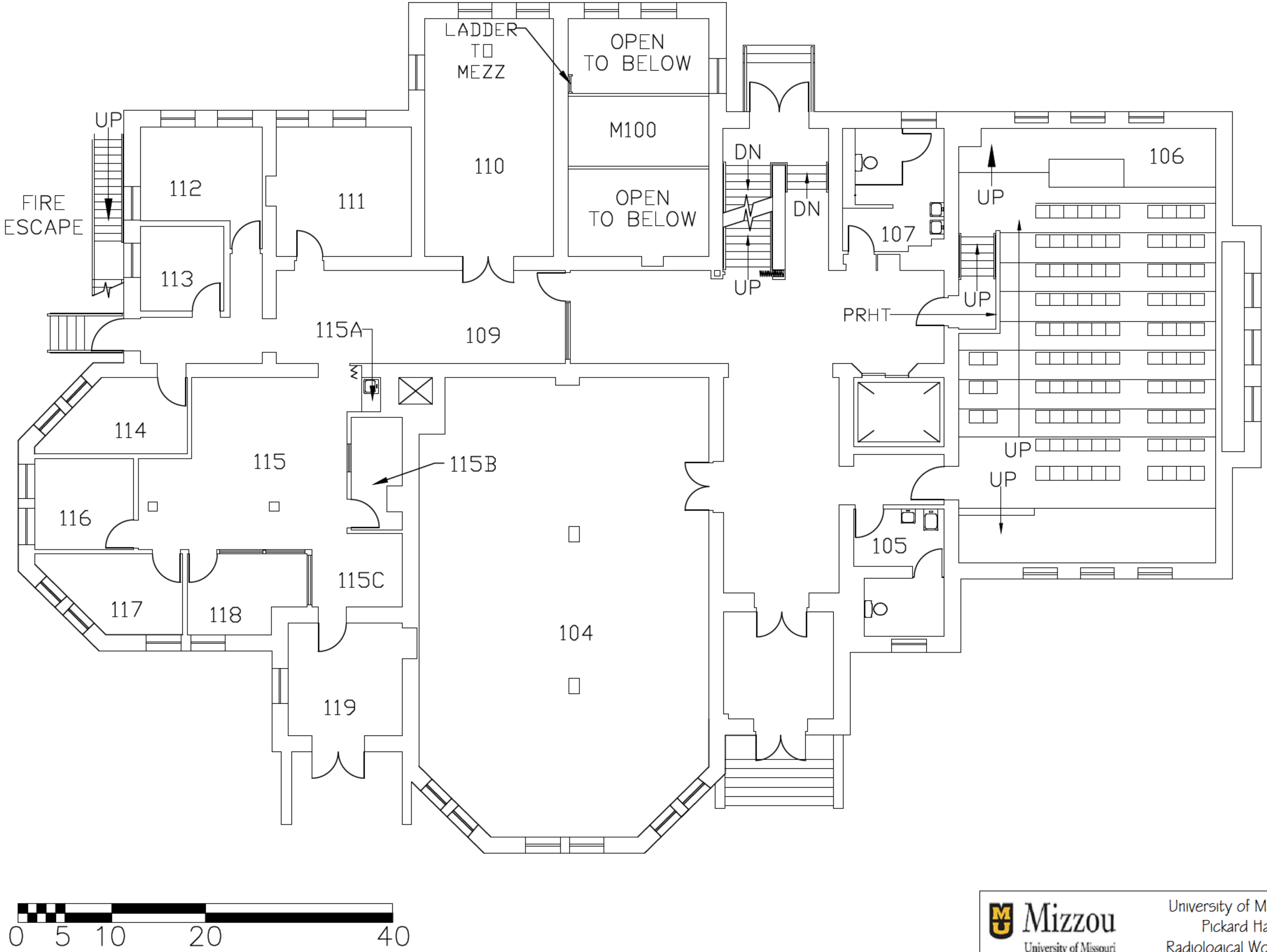


Mizzou
University of Missouri

University of Missouri
Pickard Hall
Radiological Work Plan

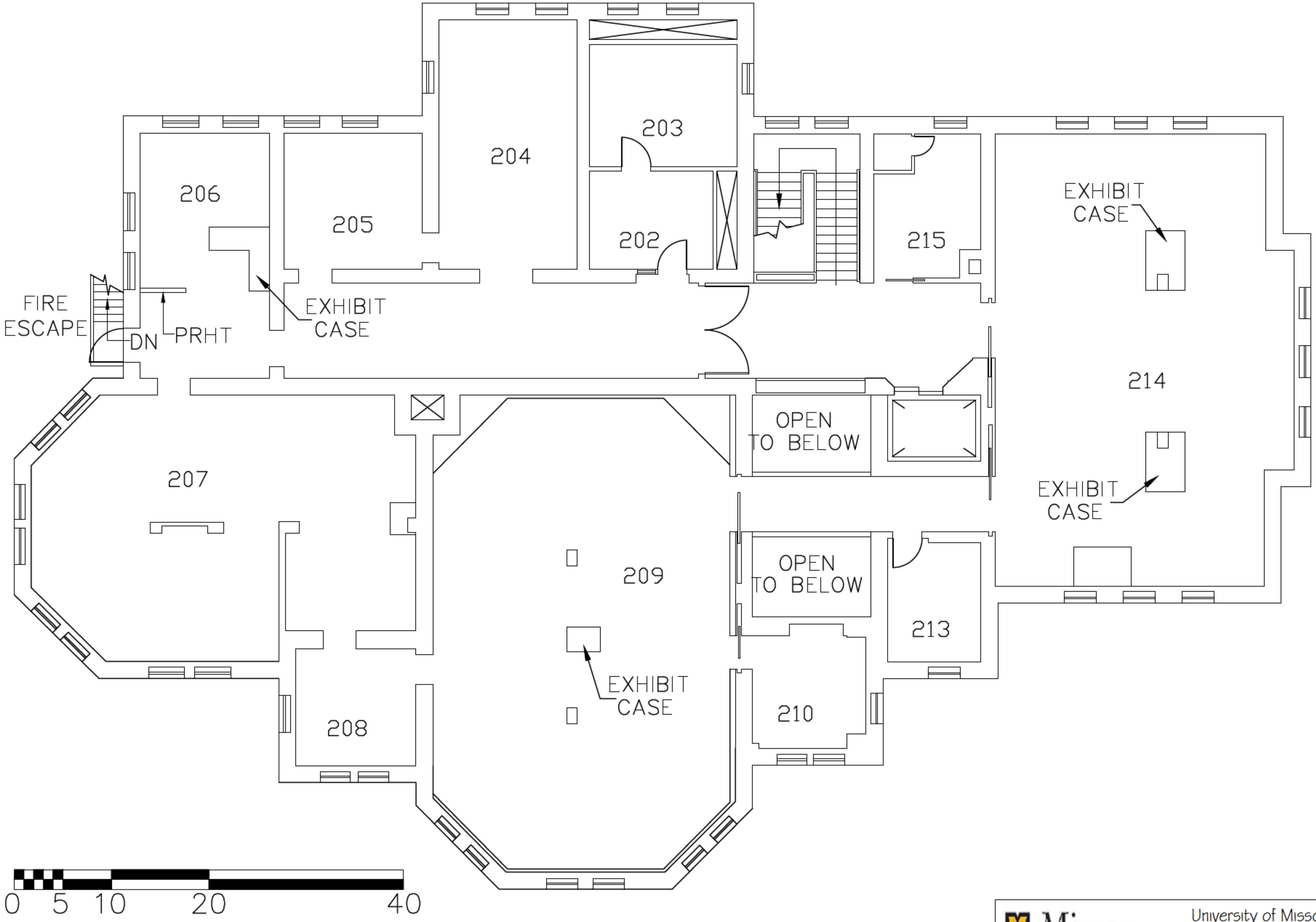
CHASE Environmental Group inc

Basement	Current Layout	Page: B.1 of B.3



University of Missouri
Pickard Hall
Radiological Work Plan

1st Floor	Current Layout	Page: B.2 of B.3



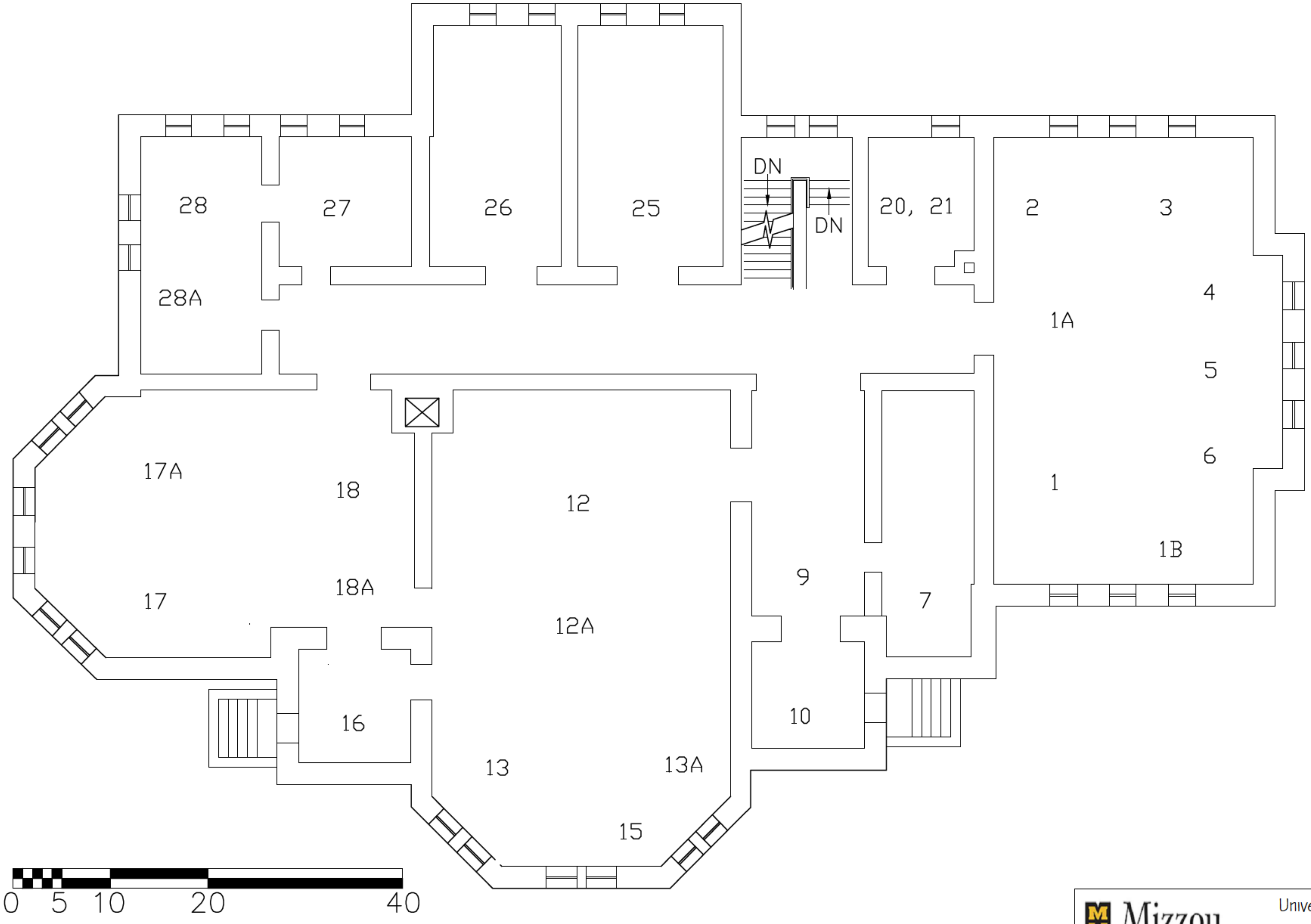
Mizzou
University of Missouri

University of Missouri
Pickard Hall
Radiological Work Plan

CHASE Environmental Group Inc

2nd Floor	Current Layout	Page: B.3 of B.3

Appendix C
Original Construction Floor Plans

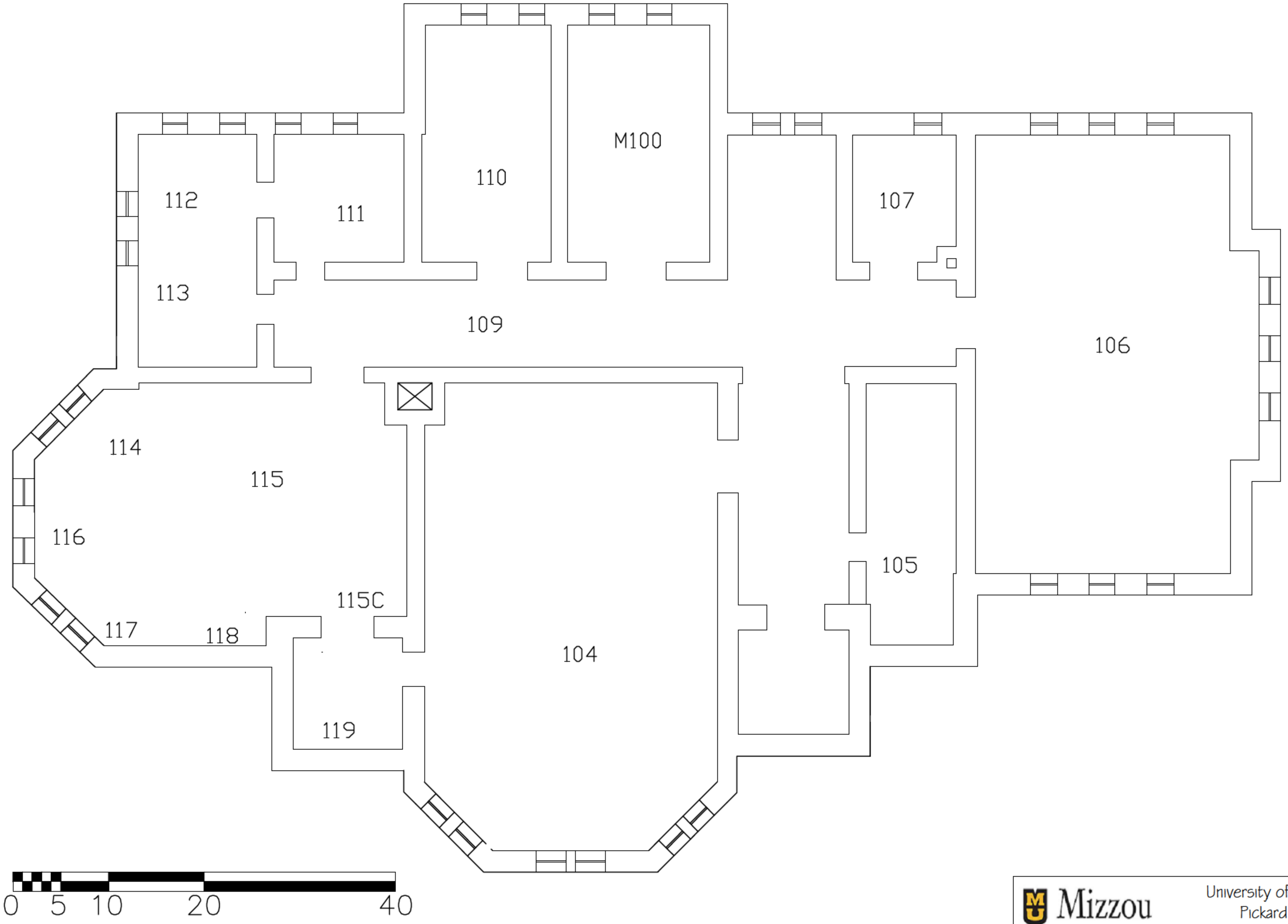


Mizzou
University of Missouri

University of Missouri
Pickard Hall
Radiological Work Plan

CHASE
Environmental Group inc

Basement	Original Layout	Page: C.1 of C.3

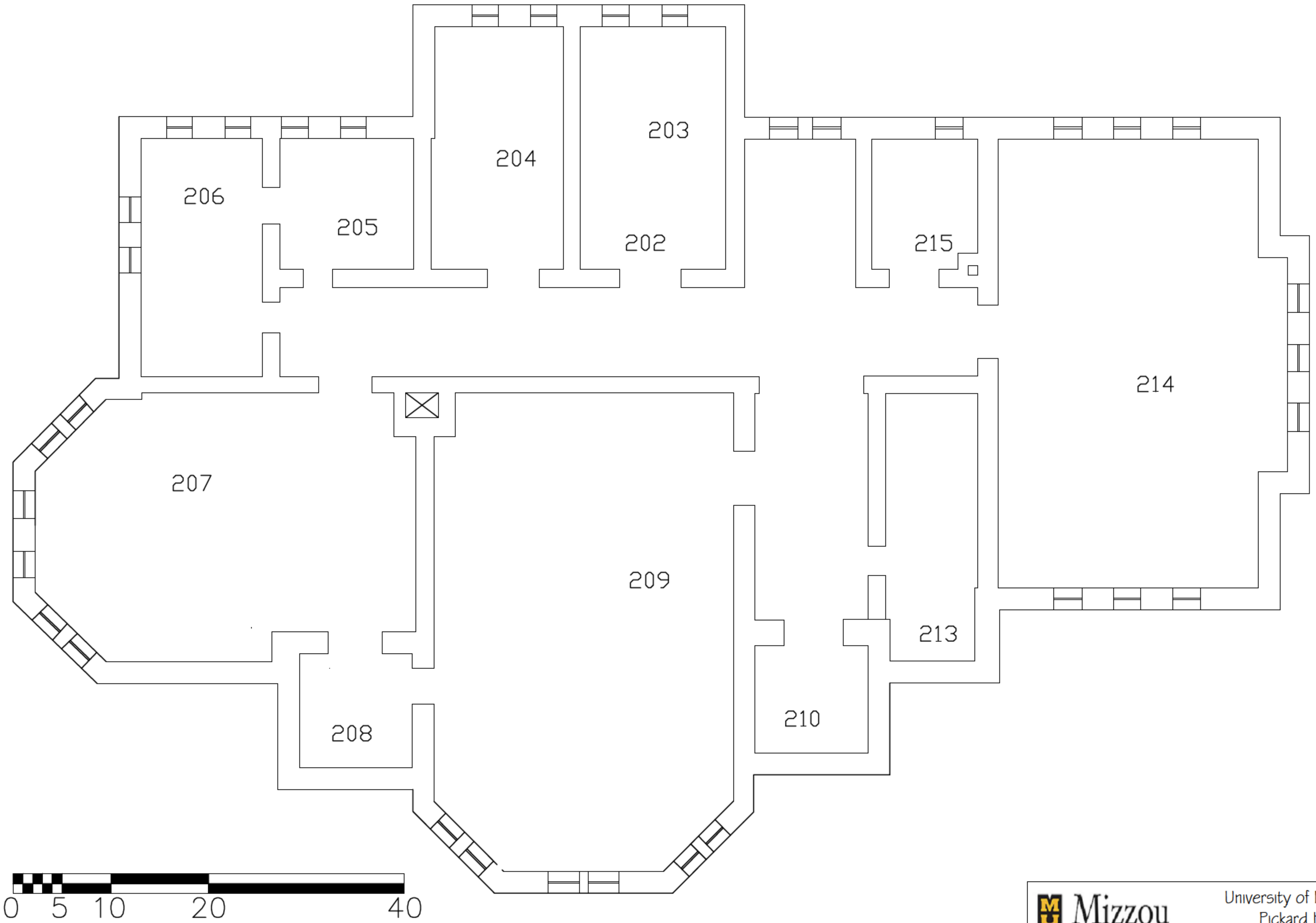


Mizzou
University of Missouri

University of Missouri
Pickard Hall
Radiological Work Plan

CHASE Environmental Group

1st Floor	Original Layout	Page: C.2 of C.3



Mizzou
University of Missouri

University of Missouri
Pickard Hall
Radiological Work Plan

CHASE
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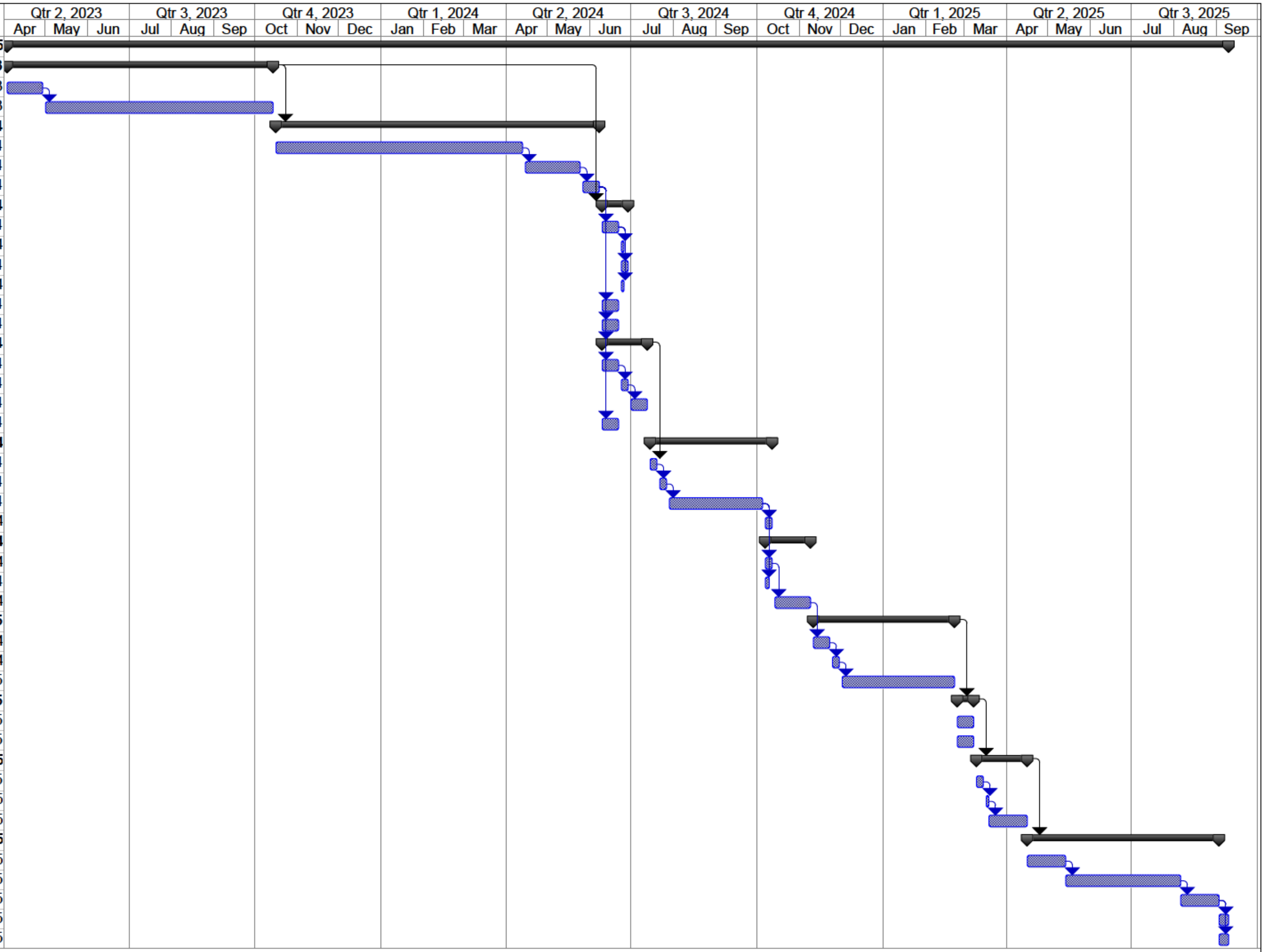
2nd Floor

Original Layout

Page: C.3 of C.3

Appendix D
Conceptual Project Schedule

ID	Task Name	Duration	Start	Finish
1	**Pickard Hall Decommissioning**	**637 days**	**Mon 4/3/23**	**Tue 9/9/25**
2	**Decommissioning Plan**	**140 days**	**Mon 4/3/23**	**Fri 10/13/23**
3	MU Submit DP to NRC	20 days	Mon 4/3/23	Fri 4/28/23
4	NRC Review and Approval	120 days	Mon 5/1/23	Fri 10/13/23
5	**Demolition Contractor Selection**	**170 days**	**Mon 10/16/23**	**Fri 6/7/24**
6	Procurement	130 days	Mon 10/16/23	Fri 4/12/24
7	Work Plans	30 days	Mon 4/15/24	Fri 5/24/24
8	Update Demolition Plan	10 days	Mon 5/27/24	Fri 6/7/24
9	**Building Preparation**	**15 days**	**Mon 6/10/24**	**Fri 6/28/24**
10	Remove Furnishings, Cabinets, Displays	10 days	Mon 6/10/24	Fri 6/21/24
11	Brick Duct Encapsulation	2 days	Mon 6/24/24	Tue 6/25/24
12	ACM Abatement	5 days	Mon 6/24/24	Fri 6/28/24
13	Universal Waste Removal	2 days	Mon 6/24/24	Tue 6/25/24
14	Isolate Utilities	10 days	Mon 6/10/24	Fri 6/21/24
15	Isolate Tunnel	10 days	Mon 6/10/24	Fri 6/21/24
16	**Site Preparation**	**25 days**	**Mon 6/10/24**	**Fri 7/12/24**
17	Truck Access	10 days	Mon 6/10/24	Fri 6/21/24
18	Fencing	5 days	Mon 6/24/24	Fri 6/28/24
19	Install Truck Monitor	10 days	Mon 7/1/24	Fri 7/12/24
20	Utility Isolation	10 days	Mon 6/10/24	Fri 6/21/24
21	**Building Demolition**	65 days	**Mon 7/15/24**	**Fri 10/11/24**
22	Mobilization and Project Setup	5 days	Mon 7/15/24	Fri 7/19/24
23	Stage Water Treatment System	5 days	Mon 7/22/24	Fri 7/26/24
24	Demolition	50 days	Mon 7/29/24	Fri 10/4/24
25	Establish Excavation Protection	5 days	Mon 10/7/24	Fri 10/11/24
26	**Excavation Characterization**	**25 days**	**Mon 10/7/24**	**Fri 11/8/24**
27	Gamma Scans and Soil Samples	5 days	Mon 10/7/24	Fri 10/11/24
28	Structures and Systems	3 days	Mon 10/7/24	Wed 10/9/24
29	Lab Analysis	20 days	Mon 10/14/24	Fri 11/8/24
30	**Characterization Report / Remediation Plan**	**75 days**	**Mon 11/11/24**	**Fri 2/21/25**
31	Chase Develop Report/Plan	10 days	Mon 11/11/24	Fri 11/22/24
32	MU Review and Submit to NRC	5 days	Mon 11/25/24	Fri 11/29/24
33	NRC Review and Approval	60 days	Mon 12/2/24	Fri 2/21/25
34	**Remediation**	**10 days**	**Mon 2/24/25**	**Fri 3/7/25**
35	Soil Remediation	10 days	Mon 2/24/25	Fri 3/7/25
36	Structure/System Remediation	10 days	Mon 2/24/25	Fri 3/7/25
37	**Final Status Surveys**	**27 days**	**Mon 3/10/25**	**Tue 4/15/25**
38	Gamma Scans and Soil Samples	5 days	Mon 3/10/25	Fri 3/14/25
39	Structures and Systems	2 days	Mon 3/17/25	Tue 3/18/25
40	Lab Analysis	20 days	Wed 3/19/25	Tue 4/15/25
41	**Final Status Report**	**100 days**	**Wed 4/16/25**	**Tue 9/2/25**
42	MU Review and Submit to NRC	20 days	Wed 4/16/25	Tue 5/13/25
43	NRC Review and Verification Surveys	60 days	Wed 5/14/25	Tue 8/5/25
44	NRC Approval of Site Release	20 days	Wed 8/6/25	Tue 9/2/25
45	Backfill and Site Restoration	5 days	Wed 9/3/25	Tue 9/9/25
46	Remove Truck Monitor	5 days	Wed 9/3/25	Tue 9/9/25



Appendix D
Conceptual Project Schedule

Task	▬	External Tasks	▬	Inactive Summary	┈	Start-only	▬	Deadline	⇩
Split	┈	External Milestone	◆	Manual Task	◇	Finish-only	▬		
Milestone	◆	Inactive Task	▬	Duration-only	┈	External Tasks	◇		
Summary	▬	Inactive Milestone	◆	Manual Summary Rollup	◆	External Milestone	▬		
Project Summary	▬	Inactive Milestone	▭	Manual Summary	◆	Progress	▬		

Appendix E
MicroShield^{TM} Output Reports

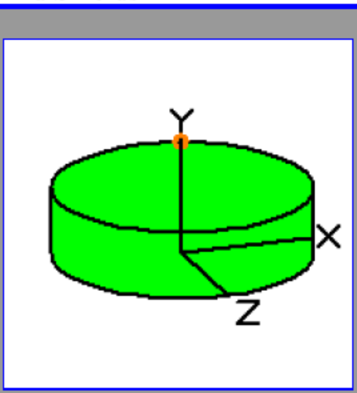
MicroShield 8.01
Chase Environmental Group (8.00-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Ra-226 Soil Scan MDC.msd	April 11, 2023	5:47:15 PM	00:00:00

Project Info	
Case Title	Pickard Hall
Description	Ra-226+C Soil Scan MDC, 1 pCi/g
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	15.0 cm (5.9 in)
Radius	28.0 cm (11.0 in)



Dose Points			
A	X	Y	Z
#1	0.0 cm (0 in)	25.0 cm (9.8 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	3.69e+04 cm^3	Concrete	1.65
Air Gap		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm^3	Bq/cm^3
Bi-210	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Bi-214	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Pb-210	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Pb-214	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Po-210	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Po-214	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Po-218	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Ra-226	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Rn-222	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002

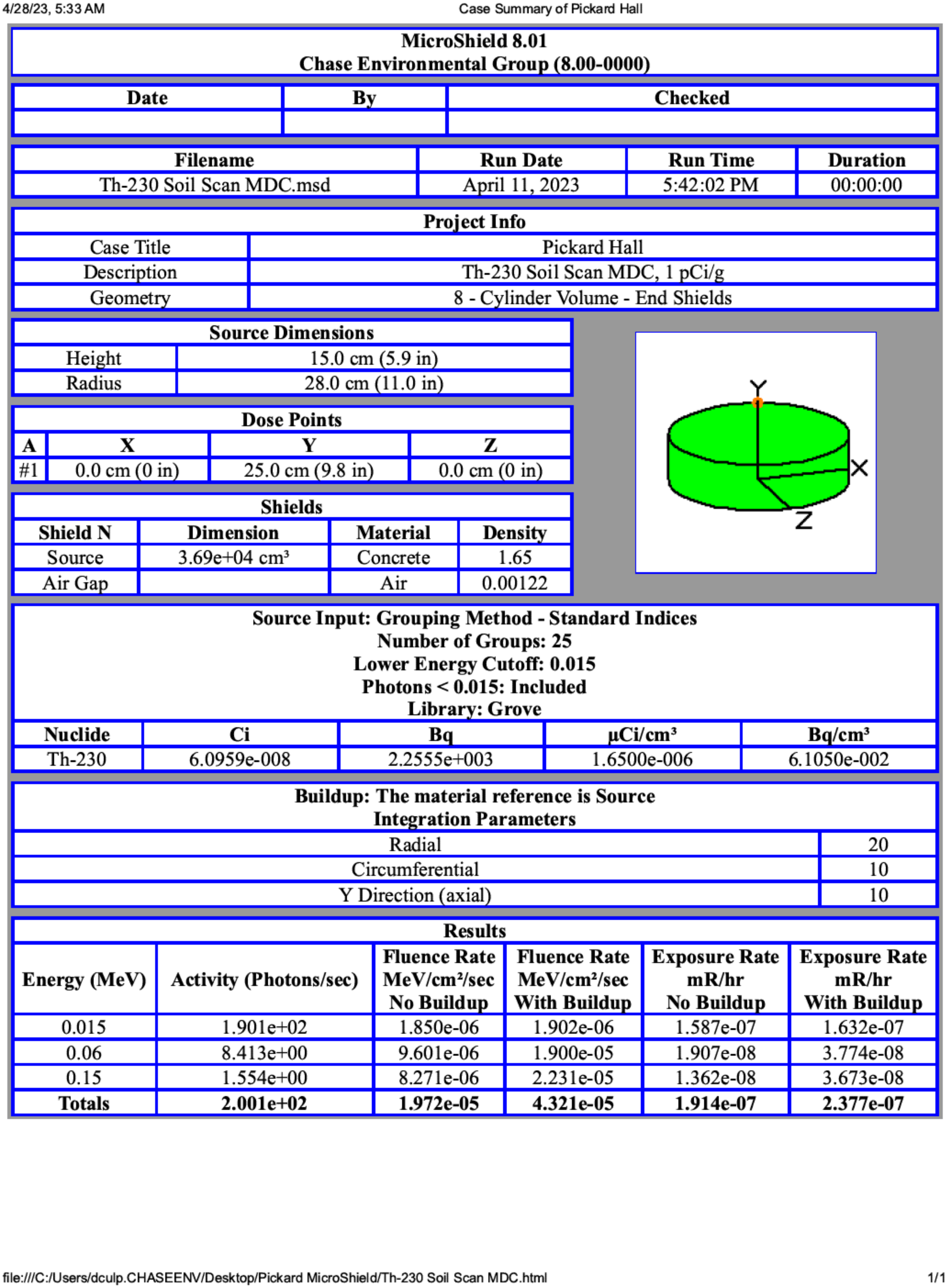
Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm^2/sec No Buildup	Fluence Rate MeV/cm^2/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	8.831e+02	8.594e-06	8.836e-06	7.371e-07	7.579e-07

0.05	1.163e+02	8.409e-05	1.377e-04	2.240e-07	3.668e-07
0.08	5.200e+02	1.067e-03	2.569e-03	1.688e-06	4.066e-06
0.1	3.061e+00	9.110e-06	2.398e-05	1.394e-08	3.669e-08
0.2	2.429e+02	1.897e-03	4.886e-03	3.348e-06	8.624e-06
0.3	4.655e+02	6.181e-03	1.428e-02	1.172e-05	2.709e-05
0.4	8.631e+02	1.670e-02	3.523e-02	3.253e-05	6.865e-05
0.5	4.029e+01	1.044e-03	2.055e-03	2.049e-06	4.034e-06
0.6	1.087e+03	3.577e-02	6.633e-02	6.981e-05	1.295e-04
0.8	2.132e+02	1.021e-02	1.736e-02	1.943e-05	3.302e-05
1.0	7.062e+02	4.527e-02	7.239e-02	8.344e-05	1.334e-04
1.5	4.294e+02	4.649e-02	6.708e-02	7.821e-05	1.129e-04
2.0	6.036e+02	9.402e-02	1.281e-01	1.454e-04	1.981e-04
Totals	**6.174e+03**	**2.587e-01**	**4.105e-01**	**4.486e-04**	**7.206e-04**



4/28/23, 5:33 AM Case Summary of Pickard Hall

MicroShield 8.01
Chase Environmental Group (8.00-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Th-230 Soil Scan MDC.msd	April 11, 2023	5:42:02 PM	00:00:00

Project Info	
Case Title	Pickard Hall
Description	Th-230 Soil Scan MDC, 1 pCi/g
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	15.0 cm (5.9 in)
Radius	28.0 cm (11.0 in)

Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	25.0 cm (9.8 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm^3	Concrete	1.65
Air Gap		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm^3	Bq/cm^3
Th-230	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm^2/sec No Buildup	Fluence Rate MeV/cm^2/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.901e+02	1.850e-06	1.902e-06	1.587e-07	1.632e-07
0.06	8.413e+00	9.601e-06	1.900e-05	1.907e-08	3.774e-08
0.15	1.554e+00	8.271e-06	2.231e-05	1.362e-08	3.673e-08
Totals	**2.001e+02**	**1.972e-05**	**4.321e-05**	**1.914e-07**	**2.377e-07**

file:///C:/Users/dculp.CHASEENV/Desktop/Pickard MicroShield/Th-230 Soil Scan MDC.html 1/1

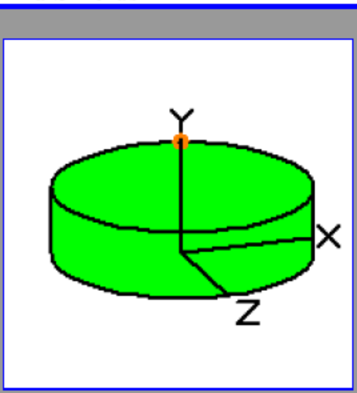
MicroShield 8.01
Chase Environmental Group (8.00-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Th-232 Soil Scan MDC.msd	May 20, 2023	10:02:19 AM	00:00:00

Project Info	
Case Title	Pickard Hall
Description	Th-232+C Soil Scan MDC, 1 pCi/g
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	15.0 cm (5.9 in)
Radius	28.0 cm (11.0 in)



Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	25.0 cm (9.8 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm^3	Concrete	1.65
Air Gap		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm^3	Bq/cm^3
Ac-228	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Bi-212	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Pb-212	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Po-212	3.9014e-008	1.4435e+003	1.0560e-006	3.9072e-002
Po-216	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Ra-224	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Ra-228	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Rn-220	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Th-228	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Th-232	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Tl-208	2.1945e-008	8.1198e+002	5.9400e-007	2.1978e-002

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm^2/sec	Fluence Rate MeV/cm^2/sec	Exposure Rate mR/hr	Exposure Rate mR/hr

		No Buildup	With Buildup	No Buildup	With Buildup
0.015	1.843e+03	1.794e-05	1.844e-05	1.538e-06	1.582e-06
0.04	2.306e+01	8.663e-06	1.199e-05	3.831e-08	5.301e-08
0.06	1.559e+01	1.780e-05	3.522e-05	3.535e-08	6.996e-08
0.08	9.735e+02	1.997e-03	4.810e-03	3.161e-06	7.612e-06
0.1	1.600e+02	4.763e-04	1.254e-03	7.287e-07	1.918e-06
0.15	9.480e+01	5.044e-04	1.360e-03	8.307e-07	2.240e-06
0.2	1.225e+03	9.567e-03	2.464e-02	1.688e-05	4.349e-05
0.3	5.882e+02	7.810e-03	1.805e-02	1.482e-05	3.423e-05
0.4	5.336e+01	1.032e-03	2.178e-03	2.011e-06	4.245e-06
0.5	3.132e+02	8.114e-03	1.597e-02	1.593e-05	3.136e-05
0.6	7.185e+02	2.363e-02	4.382e-02	4.613e-05	8.554e-05
0.8	7.189e+02	3.445e-02	5.856e-02	6.552e-05	1.114e-04
1.0	1.313e+03	8.419e-02	1.346e-01	1.552e-04	2.482e-04
1.5	3.025e+02	3.275e-02	4.726e-02	5.510e-05	7.952e-05
2.0	6.845e+00	1.066e-03	1.453e-03	1.649e-06	2.247e-06
3.0	8.104e+02	2.076e-01	2.639e-01	2.817e-04	3.581e-04
Totals	**9.161e+03**	**4.132e-01**	**6.180e-01**	**6.612e-04**	**1.012e-03**

MicroShield 8.01
Chase Environmental Group (8.00-0000)

Date	By	Checked

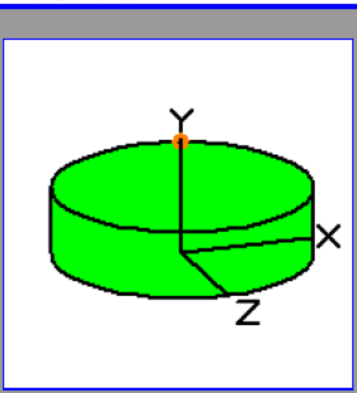
Filename	Run Date	Run Time	Duration
U Tailings Soil Scan MDC.msd	April 11, 2023	10:08:25 PM	00:00:00

Project Info

Case Title	Pickard Hall
Description	U Tailings Soil Scan MDC, 1 pCi/g
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions

Height	15.0 cm (5.9 in)
Radius	28.0 cm (11.0 in)



Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	25.0 cm (9.8 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	3.69e+04 cm³	Concrete	1.65
Air Gap		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ac-227	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Bi-211	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Pa-231	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Pa-234m	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Pb-211	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Po-215	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Ra-223	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Rn-219	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Th-227	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Th-230	6.2068e-008	2.2965e+003	1.6800e-006	6.2160e-002
Th-231	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
Th-234	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002
Tl-207	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
U-234	6.2068e-008	2.2965e+003	1.6800e-006	6.2160e-002
U-235	2.9261e-009	1.0826e+002	7.9200e-008	2.9304e-003
U-238	6.0959e-008	2.2555e+003	1.6500e-006	6.1050e-002

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	10

Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.094e+03	1.065e-05	1.095e-05	9.133e-07	9.391e-07
0.02	5.955e-01	1.820e-08	1.925e-08	6.306e-10	6.667e-10
0.03	2.604e+01	3.686e-06	4.339e-06	3.653e-08	4.301e-08
0.04	4.103e-01	1.541e-07	2.132e-07	6.816e-10	9.431e-10
0.05	1.225e+01	8.856e-06	1.450e-05	2.359e-08	3.863e-08
0.06	9.750e+01	1.113e-04	2.202e-04	2.210e-07	4.374e-07
0.08	7.103e+01	1.457e-04	3.509e-04	2.306e-07	5.553e-07
0.1	1.678e+02	4.995e-04	1.315e-03	7.641e-07	2.011e-06
0.15	3.058e+01	1.627e-04	4.388e-04	2.679e-07	7.225e-07
0.2	8.385e+01	6.548e-04	1.686e-03	1.156e-06	2.976e-06
0.3	6.529e+01	8.670e-04	2.003e-03	1.645e-06	3.800e-06
0.4	2.802e+01	5.420e-04	1.144e-03	1.056e-06	2.229e-06
0.5	5.143e-01	1.332e-05	2.623e-05	2.615e-08	5.149e-08
0.8	9.003e+00	4.314e-04	7.333e-04	8.205e-07	1.395e-06
1.0	2.172e+01	1.392e-03	2.227e-03	2.566e-06	4.104e-06
Totals	**1.709e+03**	**4.843e-03**	**1.017e-02**	**9.728e-06**	**1.930e-05**