NWMI
NORTHWEST MEDICAL ISOTOPES

NRC-006B

United States Nuclear Regulatory Commission Official Hearing Exhibit				
In the Matter of:	NORTHWEST MEDICAL ISOTOPES, LLC (Medical Radioisotope Production Facility)			
	Commission Mandatory Hearing			
Docket #:	05000609			
Exhibit #:	NRC-006B-MA-CM01		**Identified:**	1/23/2018
Admitted:	1/23/2018		**Withdrawn:**	
Rejected:			**Stricken:**	
Other:				

ATTACHMENT 3

Northwest Medical Isotopes, LLC

Docket No. 50-609

Revision 3 of Chapters 1.0 through 18.0 of NWMI-2013-021, *Construction Permit Application for Radioisotope Production*

(Document No. NWMI-2013-021, Rev. 3, September 2017)

Public Version

Information is being provided via hard copy

NORTHWEST MEDICAL ISOTOPES

Chapter 1.0 – The Facility

Construction Permit Application for Radioisotope Production Facility

NWMI-2013-021, Rev. 3
September 2017

Prepared by:
Northwest Medical Isotopes, LLC
815 NW 9th Ave, Suite 256
Corvallis, Oregon 97330

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Chapter 1.0 – The Facility

Construction Permit Application for Radioisotope Production Facility

NWMI-2013-021, Rev. 3

Date Published:
September 5, 2017

Document Number: **NWMI-2013-021**		*Revision Number*: **3**
Title: **Chapter 1.0 – The Facility Construction Permit Application for Radioisotope Production Facility**		
Approved by: **Carolyn Haass**	*Signature*: Carolyn C Haass	

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REVISION HISTORY

Rev	Date	Reason for Revision	Revised By
0	6/29/2015	Initial Application	Not required
1	5/19/2017	Incorporate changes based on responses to NRC Requests for Additional Information	C. Haass
2	N/A		
3	9/5/2017	Incorporate final comments from NRC Staff and ACRS; full document revision	C. Haass

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TERMS

Acronyms and Abbreviations

^{99}Mo	molybdenum-99
^{235}U	uranium-235
^{238}U	uranium-238
ADUN	acid deficient uranyl nitrate
ALARA	as low as reasonably achievable
BMS	building management system
CFR	Code of Federal Regulations
CSA	criticality safety analysis
Discovery Ridge	Discovery Ridge Research Park
DOE	U.S. Department of Energy
EF scale	enhanced Fujita tornado intensity scale
EOI	end of irradiation
ESF	engineered safety feature
F scale	Fujita tornado intensity scale
FEMA	Federal Emergency Management Agency
FPC	facility process control
H_2	hydrogen gas
HAZOP	hazards and operability
HEPA	high-efficiency particulate air
HMTA	hexamethylenetetramine
HVAC	heating ventilation and air conditioning
I&C	instrumentation and control
IBC	International Building Code
IROFS	items relied on for safety
ISA	integrated safety analysis
ISG	interim staff guidance
IX	ion exchange
LEU	low-enriched uranium
MMI	Modified Mercalli Intensity
Mo	molybdenum
MU	University of Missouri
MURR	University of Missouri Research Reactor
NEP	normal electric power
NO_x	nitrogen oxide
NMSZ	New Madrid Seismic Zone
NRC	U.S. Nuclear Regulatory Commission
NWMI	Northwest Medical Isotopes, LLC
OSTR	Oregon State University TRIGA Reactor
OSU	Oregon State University
PHA	preliminary hazards analysis
PUREX	plutonium-uranium extraction
QRA	quantitative risk assessment
R&D	research and development
RPF	radioisotope production facility
SEP	standby electrical power
SNM	special nuclear material
SSC	structures, systems, and components
TBP	tributyl phosphate

TCE	trichloroethylene
U	uranium
U.S.	United States
UN	uranyl nitrate
UNH	uranyl nitrate hexahydrate
[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	[Proprietary Information]
USGS	U.S. Geological Survey

Units

Ci	curie
cm	centimeter
ft	feet
ft^2	square feet
g	gram
gal	gallon
ha	hectare
hr	hour
in.	inch
kg	kilogram
km	kilometer
L	liter
lb	pound
m	meter
m^2	square meter
mi	mile
sec	second
wt%	weight percent

1.0 THE FACILITY

1.1 INTRODUCTION

Northwest Medical Isotopes, LLC (NWMI) is applying to the U.S. Nuclear Regulatory Commission (NRC) to obtain a license for a production facility under Title 10, *Code of Federal Regulations* (CFR) Part 50 (10 CFR 50), "Domestic Licensing of Production and Utilization Facilities." The 10 CFR 50 license application for the Radioisotope Production Facility (RPF) is being prepared following the guidance in NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors – Format and Content.* The NRC has determined that a radioisotope separation and processing facility, which also conducts separation of special nuclear material (SNM), will be considered a production facility and as such, will be subject to licensing under 10 CFR 50. A significant portion of the NWMI RPF involves the disassembly of irradiated low-enriched uranium (LEU) targets, separation and purification of fission product molybdenum-99 (^{99}Mo), and the recycle of LEU that is licensed under 10 CFR 50.

The proposed action is the issuance of an NRC license under 10 CFR 50 that would authorize NWMI to construct and operate a ^{99}Mo RPF at a site located in Columbia, Missouri. The RPF will:

- Receive irradiated LEU targets (from a network of university research or test reactors)
- Process irradiated LEU targets for dissolution, recovery, and purification of ^{99}Mo
- Recover and recycle LEU to minimize radioactive, mixed, and hazardous waste generation
- Treat/package wastes generated by RPF process steps to enable transport to a disposal site
- Provide areas for associated laboratory and other support activities

Additional RPF operational activities are subject to other NRC regulations, including 10 CFR 70, "Domestic Licensing of Special Nuclear Material," to receive, possess, use, and transfer SNM, and 10 CFR 30, "Rules of General Applicability to Domestic Licensing of Byproduct Material," to process and transport ^{99}Mo for medical applications. RPF operations will also include the fabrication of LEU targets, which will be licensed under 10 CFR 70 (applied for under a separate license application submittal). These targets will be shipped to NWMI's network of research or test reactors for irradiation (considered a connected action) and returned to the RPF for processing. The LEU used for production of the LEU target materials will be obtained from the U.S. Department of Energy (DOE) and from LEU reclaimed from processing the irradiated targets. Any byproduct materials produced or extracted in the RPF will be licensed under 10 CFR 30.

The overall proposed RPF activities under all NRC licenses (i.e., 10 CFR 30, 10 CFR 50, 10 CFR 70) will include:

- Receiving LEU from the DOE
- Producing LEU target materials and fabrication of targets
- Packaging and shipping LEU targets to the university reactor network for irradiation
- Returning irradiated LEU targets for dissolution, recovery, and purification of ^{99}Mo
- Recovering and recycling LEU to minimize radioactive, mixed, and hazardous waste generation
- Treating/packaging wastes generated by RPF process steps to enable transport to a disposal site

The schedule for proposed RPF construction, operation, and decommissioning is as follows:

- Start date of site preparation/construction: Second quarter 2018
- End date of construction: Second quarter 2019
- Start date of facility startup and cold commissioning (pre-operational): Third quarter 2019
- Date of hot commissioning and commercial operations: Fourth quarter 2019/first quarter 2020
- Date of decommissioning: 2050

1.2 SUMMARY AND CONCLUSIONS ON PRINCIPAL SAFETY CONSIDERATIONS

This section identifies safety criteria, principal safety considerations, and conclusions for the RPF structures, systems, and components (SSC).

1.2.1 Radioisotope Production Facility Special Nuclear Material Inventory

The RPF SNM inventory is summarized below based on material accountability areas. The RPF target fabrication area is governed by 10 CFR 70 and summarized in Table 1-1. Some locations may contain SNM in multiple forms. For example, the LEU can rack may include some containers of uranium metal pieces, while others may contain LEU target material [Proprietary Information]. The material physical form will affect the SNM mass that may be present in the storage location. The dissolver process enclosure will include uranium metal that is being dissolved to produce uranyl nitrate (UN) solution. Composition ranges indicate the variation of solution compositions present in different vessels at a particular location.

Table 1-1. Special Nuclear Material Inventory of Target Fabrication Area

Location[a]	Form	Concentration	Volume	SNM mass[b]	
				Bounding[c,d]	Nominal[c,d]
[Proprietary Information]	Solid U-metal pieces/LEU target material in sealed containers	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Dissolver process enclosure	U-metal/UNH	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Recycled uranium process enclosures	UNH	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
ADUN concentration and storage process enclosures	ADUN	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Wash column and drying tray enclosures	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

[a] All process enclosures and storage systems are located in the target fabrication process area.

[b] SNM concentration and mass represent total amount of LEU (combined ^{235}U and ^{238}U at $\leq$19.95 wt% ^{235}U).

[c] [Proprietary Information]

[d] The indicated masses are not additive to describe the total 10 CFR 70 area inventory because material is transferred from one location to another during a processing week.

[e] [Proprietary Information]

ADUN = acid deficient uranyl nitrate.
LEU = low-enriched uranium.
N/A = not applicable.
SNM = special nuclear material.
U = uranium.
UNH = uranyl nitrate hexahydrate.
[Proprietary Information]

Bounding and nominal SNM inventories are indicated on Table 1-1 and shown in terms of the equivalent mass of uranium, independent of the physical form. The bounding inventory in each location is based on the full vessel capacity and composition of in-process solution. The nominal inventory is based on the assumption that storage areas are generally operated at half capacity to provide a buffer for potential variations in process throughput during normal operation. Summation of the location inventories does not necessarily provide an accurate description of the total target fabrication area inventory due to the batch processing operation. Material from one process location is used as input to a subsequent location so that material cannot be present in all locations at the indicated inventories under normal operating conditions.

Irradiated material areas are governed by 10 CFR 50 and summarized in Table 1-2. Equipment and vessels containing SNM will be located in a variety of hot cells within the RPF. Multiple forms are shown for the target dissolution hot cell because material entering as [Proprietary Information] is dissolved to produce UN solution.

Table 1-2. Special Nuclear Material Inventory of Irradiated Material Areas

Location	Form	Concentration	Volume	SNM mass[a]	
				Bounding[b,c]	Nominal[c,d]
Target receipt hot cell	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Target disassembly hot cells[e]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Target dissolution hot cells[e]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Mo recovery and purification hot cells	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Tank hot cell					
Mo recovery tanks	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Impure U collection tanks	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
IX columns and support tanks	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Uranium concentrator #1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Uranium concentrator #2	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
U decay tanks	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
U IX waste tanks	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
High dose liquid accumulation[g]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Solid waste vessels[h]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

[a] SNM concentration and mass represent total amount of LEU (combined ^{235}U and ^{238}U at ≤ 19.95 wt% ^{235}U).
[b] [Proprietary Information]
[c] The indicated masses are not additive to describe the total 10 CFR 50 area inventory, as the material is transferred from one location to another during a processing week.
[d] [Proprietary Information]
[e] [Proprietary Information]
[f] [Proprietary Information]
[g] [Proprietary Information]
[h] [Proprietary Information]

IX	=	ion exchange.
LEU	=	low-enriched uranium.
Mo	=	molybdenum.
MURR	=	University of Missouri Research Reactor.
N/A	=	not applicable.
OSTR	=	Oregon State University TRIGA Reactor.
SNM	=	special nuclear material.
U	=	uranium.
UNH	=	uranyl nitrate hexahydrate solution.
[Proprietary Information]		

Bounding and nominal SNM inventories are indicated on Table 1-2 and shown in terms of the equivalent mass of uranium, independent of the physical form. The bounding inventory in each location is based on operation at the weekly maximum system capacity and approximates the condition where most vessels are filled to capacity with material at a composition of the in-process solution.

The nominal inventory in each location is based on operation at the weekly system throughput when processing the dominant annual target load. Multiple locations indicate a range for solution concentrations and volumes describing the variations over bounding and nominal conditions.

Summation of the location inventories does not necessarily provide an accurate description of the total irradiated material area inventory due to the batch processing operation. Material from one process location is used as input to a subsequent location such that material cannot be present in all locations at the indicated inventories under normal operating conditions.

1.2.2 Consequences from the Operation and Use of the Facility

The primary consequences resulting from the operation of the RPF operations are radiological. The RPF will produce LEU target material that will then be irradiated in a network of university reactors. After the LEU target material is irradiated, the material will transported back to the RPF and processed in the RPF to extract and purify the ^{99}Mo. Radioactive waste materials will be processed and/or converted to solid wastes for shipment to off-site disposal facilities. The RPF is designed to be a zero radioactive liquid effluent discharge facility.

The anticipated radionuclide inventory in the RPF is based on a weekly throughput of [Proprietary Information]. The maximum radionuclide inventory is based on the accumulation in the various systems dependent on the process material decay times, as noted in Table 1-3. Table 1-3 provides the calculated radionuclide inventory (curies [Ci]) for the different process streams in the RPF. The radionuclide inventory values are discussed further in the Radiological Hazards subsections (Chapter 4.0, "Radioisotope Production Facility Description," Section 4.3.x.5) of each RPF process area.

Table 1-3. Radionuclide Inventory for Radioisotope Production Facility Process Streams

System	Ci	Time (hr EOI)
Target dissolution	[Proprietary Information]	[Proprietary Information]
Mo feed tanks	[Proprietary Information]	[Proprietary Information]
U system	[Proprietary Information]	[Proprietary Information]
Mo system	[Proprietary Information]	[Proprietary Information]
Mo waste tank	[Proprietary Information]	[Proprietary Information]
Offgas system[a]	[Proprietary Information]	[Proprietary Information]
High-dose waste tanks[c]	[Proprietary Information]	[Proprietary Information]
Uranium recycle[d]	[Proprietary Information]	[Proprietary Information]

[a] Offgas system radionuclide inventory is based on NWMI-2013-CALC-011[b] to account for accumulation of isotope buildup in the offgas system. [Proprietary Information]

[b] Material decay time is based on the total equilibrium in-process inventory, as described in NWMI-2013-CALC-011, *Source Term Calculations*, Rev. A, Northwest Medical Isotopes, LLC, Corvallis, Oregon, 2015.

[c] [Proprietary Information]

[d] [Proprietary Information]

EOI = end of irradiation.
IX = ion exchange.
Mo = molybdenum.
U = uranium.

Figure 1-1 shows the anticipated radionuclide inventory and provides a color key indicating the amount of curies for the different process areas depending on the EOI.

[Proprietary Information]

Figure 1-1. Radioisotope Processing Facility at 0 to 40 Hours End of Irradiation

Figure 1-2 shows the anticipated maximum radionuclide inventory in the RPF at the completion of processing [Proprietary Information] at an operation time greater than 40 hr EOI.

[Proprietary Information]

Figure 1-2. Radioisotope Processing Facility at Greater than 40 Hours End of Irradiation

As a result of working with radioactive materials, the RPF workers will receive occupational exposures, and members of the public will receive some exposure from the release and shipment of the produced materials. Doses to workers and the public during normal operation are within the limits of 10 CFR 20.1201, "Occupational Dose Limits for Adults," and 10 CFR 20.1301, "Dose Limits for Individual Members of the Public," respectively. In addition, there are potential exposures to the public from postulated accidents. Potential doses to workers and the public from postulated accident are within the limits of 10 CFR 20.1201 and 10 CFR 20.1301, respectively.

1.2.3 Radioisotope Production Facility Integrated Safety Analysis

NWMI evaluated the safety of the facility using an integrated safety analysis (ISA) process. The ISA process comprises a preliminary hazards analysis (PHA) and the follow-on development and completion of quantitative risk assessments (QRA) to address events and hazards identified in the PHA as requiring further evaluation.

The ISA process flow diagram is provided Figure 1-3. The ISA process (being adapted for this application) consists of conducting a PHA of a system using a combination of written process descriptions, process flow diagrams, process and instrumentation diagrams, and supporting calculations to identify events that could lead to adverse consequences. Those adverse consequences are evaluated qualitatively by the ISA team members to identify the likelihood and severity of consequences using guidance on event frequencies and consequence categories consistent with the regulatory guidelines.

Each event with an adverse consequence that involves licensed material or its byproducts is evaluated for risk using a risk matrix that enables the user to identify unacceptable intermediate- and high-consequence risks. For these unacceptable intermediate- and high-consequence risks events, items relied on for safety (IROFS) are developed to prevent or mitigate the consequences of the events, and an event tree analysis is used to demonstrate that the risk can be reduced to acceptable frequencies through preventative or mitigative IROFS.

Fault trees and failure mode and effects analysis can be used to (1) provide quantitative failure analysis data (failure frequencies) for use in the event tree analysis of the IROFS, as necessary, or (2) quantitatively analyze an event from its basic initiators to demonstrate that the quantitative failure frequency is already highly unlikely under normal standard industrial conditions, thus not needing the application of IROFS. Once the IROFS are developed, management measures are identified to ensure that the IROFS failure frequency used in the analysis is preserved and the IROFS are able to perform the intended functions when needed.

Additional detailed information is provided in Chapter 13.0, "Accident Analysis" and NWMI-2015-SAFETY-002, *Radioisotope Production Facility Integrated Safety Analysis Summary*.

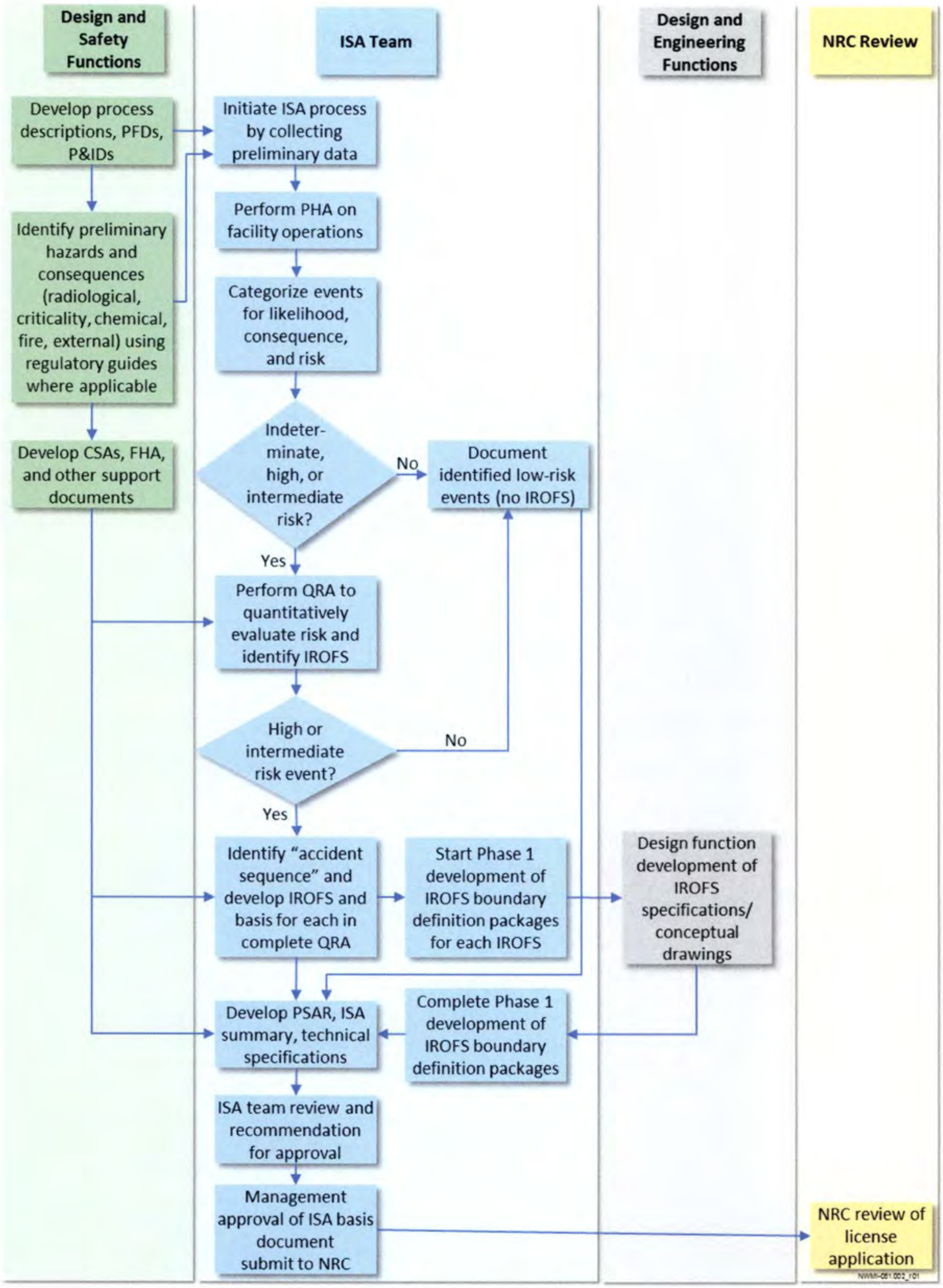

Figure 1-3. Integrated Safety Analysis Process Flow Diagram

1.2.3.1 Items Relied on for Safety Boundary Definition Package and Technical Specifications Development

One of the outcomes of the ISA process is the development of ISA baseline documents that will be used to develop the preliminary safety analysis report, license application, and technical specifications (and following construction, the final safety analysis report). These ISA baseline documents will include process descriptions, process flow diagrams, process and instrumentation diagrams, supporting calculations (e.g., release consequences, dose consequences, shielding calculations, etc.), PHAs, criticality safety evaluations, fire hazards analysis, QRAs, and other evaluations of specific topics (e.g., natural phenomenon strengths, man-made accident frequencies, support structure evaluations, etc.) supporting conclusions in the ISA not covered in the above documents. Where IROFS are developed from the ISA process, an IROFS boundary definition package will be developed to incorporate relevant information from all of these documents into one place for each IROFS.

These IROFS boundary definition packages are living documents that will be updated throughout the construction phase and operating life of the facility as changes to the implementation of IROFS and their management measures evolve. Using the IROFS boundary definition package, an ISA team member will prepare the technical specifications and the IROFS summary. During the NRC licensing review, operational readiness review, and periodic NRC inspections, the NRC staff will review the IROFS boundary definition packages to ensure that the IROFS are maintained, reliable, and available when needed.

1.2.3.1.1 Items Relied on for Safety Boundary Definition Package Development

As living documents, the IROFS boundary definition packages will be developed in the following phases.

Phase 1: Initial development phase – During initial development of the IROFS during conceptual and preliminary design, the safety function (including safety limits, limiting safety system settings, human factors engineering and human-system interface requirements, design standards, and initial management measures) will be documented. This level of completion will provide the designers with the information needed to create the final design of the IROFS. This level of completion will also provide support for the technical specifications and NRC review of the initial construction license.

Phase 2: Final design phase – All sections of the IROFS boundary definition package will be completed, including drawings approved for construction or fabrication. Exceptions include reference to the actual versions of the training program and procedures. This level of completion is required before construction, fabrication, and testing of passive engineered controls, active engineered controls, and augmented administrative controls-type IROFS. For augmented administrative controls and simple administrative controls-type IROFS, this level is required to proceed with training and procedure completion and approval. At this level of completion, NWMI should have a basis for any license amendments that need to be approved before implementation. NRC license amendments must be approved before initiation of construction, fabrication, and testing.

Phase 3: Implementation phase – Applicable training and procedures (operating and maintenance/ surveillance) will be referenced and logs of NRC inspection reports, audit findings, and event notifications made against each IROFS will be maintained. This level of completion will support the initial testing and operations of the facility and the NRC operational readiness review.

1.2.3.1.2 Technical Specification Development

The technical specifications will be developed from the IROFS boundary definition packages. The ISA team will review the completed document, and the ISA Manager and RPF Operations Manager will approve the changes to the technical specifications. The NRC must review and approve any changes to the technical specifications.

A PHA was performed to support the RPF Construction Permit Application and is documented in NWMI-2015-SAFETY-001, *NWMI Radioisotope Production Facility Preliminary Hazards Analysis*. The following sections summarize the PHA results. Additional detailed information is provided in Chapter 13.0.

1.2.3.2 Hazard and Accident Analysis

1.2.3.2.1 Description of Processes Analyzed

Process descriptions used by the PHA are provided in Section 1.3.2.2. The PHA evaluated the system hazards using the eight nodes in Table 1-4 to describe the RPF primary processes and systems. The target fabrication process is represented by Node 1.0.0. The target disassembly and target dissolution processes are represented by Nodes 6.0.0 and 2.0.0, respectively. The molybdenum (Mo) recovery and purification process is represented by Node 3.0.0, and the uranium (U) recovery and recycle process is represented by Node 4.0.0. The waste handling system process is represented by Node 5.0.0. Ventilation systems are represented by Node 7.0.0. Node 8.0.0 represents other facility hazards, including natural phenomena, man-made external events, and other facility operations not specifically covered by the process systems.

Table 1-4. Preliminary Hazard Analysis Nodes

Node	System/Process
1.0.0	Target fabrication process
2.0.0	Target dissolution process
3.0.0	Mo recovery and purification process
4.0.0	U recovery and recycle process
5.0.0	Waste handling system process
6.0.0	Target disassembly
7.0.0	Ventilation system
8.0.0	Natural phenomena, man-made external events, and other facility operations

Mo = molybdenum.
U = uranium.

1.2.3.2.2 Identification of Hazards

Initial hazards identified by preliminary reviews included:

- High radiation dose to workers and the public from irradiated target material during processing
- High radiation dose due to accidental nuclear criticality
- Toxic uptake of licensed material by workers or the public during processing or accidents
- Fires and explosions associated with chemical reactions and use of combustible materials and flammable gases
- Chemical exposures associated with chemicals used in processing the irradiated target material
- External events (both natural and man-made) that impact the facility operations

The primary nodes shown in Table 1-4 were further subdivided to describe subsystems or subprocess elements and basic design functions for hazards identification. A methodology was selected from the alternate techniques described in Chapter 13.0 and NWMI-2015-SAFETY-002 for analysis of the hazards at each lower-tier node based on the status of the current design maturity.

In general, the design status available for the RPF Construction Permit Application basis resulted in selection of what-if, structured what-if, or hazards and operability (HAZOP) analysis methodologies for the identification of hazards and determination of whether a hazard would pose an unacceptable risk. Hazards that posed an unacceptable risk were used as input to define accident sequences for further evaluation.

1.2.3.3 Description of Accident Sequences

Each of the following accident initiating events was included in the PHA.

- Criticality accident
- Loss of electrical power
- External events (meteorological, seismic, fire, flood)
- Critical equipment malfunction
- Operator error
- Facility fire (explosion is included in this category)
- Any other event potentially related to unique facility operations

The PHA identifies and categorizes accident sequences that require further evaluation. Table 1-5 defines the top-level accident sequence notation used in the RPF PHA.

Table 1-6 provides a crosswalk between the PHA top-level accident sequence categories and the NUREG-1537, Part 1 Interim Staff Guidance (ISG) accident initiating events (NRC, 2012). As noted at the bottom of Table 1-6, PHA accident sequences involve one or more of the NUREG-1537 Part 1 ISG accident initiating event categories, as noted by ✓ in the corresponding table cell, but the PHA accident sequences themselves are not necessarily initiated by the ISG accident initiating event. Table 1-6 shows how PHA accident sequences correspond with ISG accident initiating events, and demonstrates that the PHA considers the full range of accident events identified in the ISG.

Table 1-5. Radioisotope Production Facility Preliminary Hazard Analysis Accident Sequence Category Designator Definitions

PHA top-level accident sequence category[a]	Definition
S.C.	Criticality
S.F.	Fire or explosion
S.R.	Radiological
S.M.	Man-made
S.N.	Natural phenomena
S.CS.	Chemical safety

[a] The alpha category designator is followed in the PHA by a two-digit number "XX" that refers to the specific accident sequence (e.g., S.C.01, S.F.07).

PHA = preliminary hazard analysis.

Table 1-6. Crosswalk of NUREG-1537 Part 1 Interim Staff Guidance Accident Initiating Events versus Radioisotope Production Facility Preliminary Hazards Analysis Top-Level Accident Sequence Categories (2 pages)

NUREG-1537[a] Part 1 ISG accident initiating event category	PHA top-level accident sequence category[b] S.C. (criticality)	S.F. (fire)	S.R. (radiological)	S.M. (man-made)	S.N. (natural phenomena)	S.CS. (chemical safety)
Criticality accident	✓	✓			✓	
Loss of electrical power			✓		✓	
External events (meteorological, seismic, fire, flood)	✓	✓		✓	✓	✓
Critical equipment malfunction	✓	✓	✓	✓		✓
Operator error	✓		✓	✓		✓
Facility fire (explosion is included in this category)		✓	✓			
Any other event potentially related to unique facility operations	✓		✓	✓		

[a] NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors – Format and Content*, Part 1, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, D.C., February 1996.

[b] PHA accident sequences involve one or more of the NUREG-1537 Part 1 ISG accident initiating event categories, as noted by an ✓ in the corresponding table cell, but the PHA sequences themselves are not necessarily initiated by the ISG accident initiating event.

ISG = Interim Staff Guidance. PHA = preliminary hazard analysis.

Table 1-7 provides a crosswalk that identifies the applicability of RPF PHA top-level accident sequence categories to the primary process nodes. The information in this table is referenceable to Table 1-6 and ultimately shows the relationship between the PHA process nodes and the NUREG-1537 Part 1 ISG accident initiating event categories via the PHA top-level accident scenario categories.

All process system nodes were analyzed, as described in Section 1.2.3.2.2, with special emphasis on criticality, radiological, and chemical safety hazards. Fire safety issues are addressed in every node and addressed generally in Node 8.0.0. Fire safety issues include the explosive hazard associated with hydrogen gas generation via radiolytic decomposition of water in process solutions and due to certain chemical reactions encountered during dissolution processes. Most hot cell processing areas contain very few combustible materials, both transient and fixed.

The RPF PHA identified adverse events described in NWMI-2015-SAFETY-002, Sections 4.3.1.1 through 4.3.1.7. Adverse events are identified as:

- Standard industrial events that do not involve licensed material
- Acceptable accident sequences that satisfy performance criteria by being low consequence and/or low frequency
- Unacceptable accident sequences that require further evaluation via the QRA process

Table 1-7. Crosswalk of Radioisotope Production Facility Preliminary Hazards Analysis Process Nodes and Top-Level Accident Sequence Categories

	PHA top-level accident sequence category					
Primary process node	S.C. (criticality)	S.F. (fire)	S.R. (radiological)	S.M. (man-made)	S.N. (natural phenomena)	S.CS. (chemical safety)
Target fabrication (Node 1.0.0)	✓	✓	✓			
Target dissolution (Node 2.0.0)	✓	✓	✓			
Mo recovery and purification (Node 3.0.0)	✓	✓	✓			
U recovery and recycle (Node 4.0.0)	✓	✓	✓			
Waste handling system (Node 5.0.0)	✓	✓	✓			
Target receipt and disassembly (Node 6.0.0)	✓		✓			
Ventilation system (Node 7.0.0)	✓	✓	✓			
Natural phenomena, man-made external events, and other facility operations (Node 8.0.0)	✓	✓	✓	✓	✓	✓

Note: The ✓ in a table cell indicates that the accident sequence category applies to the process node. If it does not, the cell is blank.

Mo = molybdenum. U = uranium.
PHA = preliminary hazards analysis.

An accident sequence number is assigned to each accident initiator that results in the same, or similar, bounding accident sequence results and consequences. The same accident sequence designator can appear in multiple nodes. (Table 1-5 provides definitions of accident sequence category designators.)

1.2.3.4 Characterization of High and Intermediate Consequence Accident Sequences

A total of 75 accident sequences identified for further evaluation by the PHA were analyzed for the Construction Permit Application. The accidents are analyzed in nine separate QRAs, including:

- NWMI-2015-SAFETY-003, *Quantitative Risk Analysis of Chemical Safety Process Upsets*
- NWMI-2015-SAFETY-004, *Quantitative Risk Analysis of Process Upsets Associated with Passive Engineering Controls Leading to Accident Criticality Accident Sequences*
- NWMI-2015-SAFETY-005, *Quantitative Risk Analysis of Criticality Accident Sequences that Involve Uranium Entering a System Not Intended for Uranium Service*
- NWMI-2015-SAFETY-006, *Quantitative Risk Analysis of Criticality Accident Sequences that Involve High Uranium Content in Side Waste Streams*
- NWMI-2015-SAFETY-007, *Quantitative Risk Analysis of Facility Fires and Explosions Leading to Uncontrolled Release of Fissile Material, High and Low Dose Radionuclides*
- NWMI-2015-SAFETY-008, *Quantitative Risk Analysis of Radiological Accident Sequences in the Confinement Boundaries (Including Ventilation Systems) for the NWMI Radioisotope Production Facility*

- NWMI-2015-SAFETY-009, *Quantitative Risk Analysis of Administratively Controlled Enrichment, Mass, Container Volume, and Interaction Limit Process Upsets Leading to Accidental Criticality Accident Sequences*
- NWMI-2015-SAFETY-010, *Quantitative Risk Analysis of Receipt and Shipping Events*
- NWMI-2015-SAFETY-011, *Quantitative Risk Analysis of Natural Phenomenon and Man-Made Events on Safety Features and Items Relied on for Safety*

A summary of the accidents analyzed is provided in in Chapter 13.0 and includes each accident sequence number, a descriptive title of the accident, and IROFS identified (if needed) to prevent or mitigate the consequences of the accident sequence. The preliminary IROFS selected to meet the performance criteria of 10 CFR 70.61, "Performance Requirements," are provided in Chapter 13.0 and NWMI-2015-SAFETY-002.

IROFS are identified using the following designator naming convention:

- RS-XX Radiation safety IROFS
- CS-XX Criticality safety IROFS
- FS-XX Facility safety IROFS (protecting from external events)
- FP-XX Fire protection IROFS
- CE-XX Chemical exposure IROFS

1.2.3.5 Radioisotope Production Facility Items Relied on For Safety

Table 1-8 provides a summary of the IROFS identified by the accident analyses in Chapter 13.0, and a crosswalk to where the IROFS are described in this Construction Permit Application. Chapter 13.0 also provides the associated detailed descriptions. Table 1-8 also identifies whether the IROFS are considered engineered safety feature (ESF) or administrative controls. Additional IROFS may be identified (or the current IROFS modified) during the RPF final design and development of the Operating License Application.

Table 1-8. Summary of Items Relied on for Safety Identified by Accident Analyses (3 pages)

IROFS designator	Descriptor	ESF	AC	Construction Permit Application crosswalk (primary references)
RS-01	Hot cell liquid confinement boundary	✓		Chapter 6.0, Sections 6.2.1.1 – 6.2.1.6 Chapter 13.0, Section 13.2.2.8
RS-02	Reserved[a]			
RS-03	Hot cell secondary confinement boundary	✓		Chapter 6.0, Sections 6.2.1.1 – 6.2.1.6 Chapter 13.0, Sections 13.2.2.8, 13.2.3.8
RS-04	Hot cell shielding boundary	✓		Chapter 6.0, Sections 6.2.1.1 – 6.2.1.6 Chapter 13.0, Sections 13.2.2.8, 13.2.4.8
RS-05	Reserved[a]			
RS-06	Reserved[a]			
RS-07	Reserved[a]			
RS-08	Sample and analysis of low-dose waste tank dose rate prior to transfer outside the hot cell shielded boundary		✓	Chapter 13.0, Section 13.2.7.1

Table 1-8. Summary of Items Relied on for Safety Identified by Accident Analyses (3 pages)

IROFS designator	Descriptor	ESF	AC	Construction Permit Application crosswalk (primary references)
RS-09	Primary offgas relief system	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.3.8
RS-10	Active radiation monitoring and isolation of low-dose waste transfer	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.7.1
RS-11	Reserved[a]			
RS-12	Cask containment sampling prior to closure lid removal		✓	Chapter 13.0, Section 13.2.7.1
RS-13	Cask local ventilation during closure lid removal and docking preparations	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.7.1
RS-14	Reserved[a]			
RS-15	Cask docking port enabling sensor	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.7.1
CS-01	Reserved[a]			
CS-02	Mass and batch handling limits for uranium metal, uranium oxides, targets, and laboratory sample outside process systems		✓	Chapter 13.0, Section 13.2.7.2
CS-03	Interaction control spacing provided by administrative control		✓	Chapter 13.0, Section 13.2.7.2
CS-04	Interaction control spacing provided by passively designed fixtures and workstation placement	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2
CS-05	Container batch volume limit		✓	Chapter 13.0, Section 13.2.7.2
CS-06	Pencil tank, vessel, or piping safe geometry confinement using the diameter of tanks, vessels, or piping	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.4.8
CS-07	Pencil tank and vessel spacing control using fixed interaction spacing of individual tanks or vessels	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.2.8
CS-08	Floor and sump geometry control of slab depth, sump diameter or depth for floor spill containment berms	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.2.8
CS-09	Double-wall piping	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.2.8
CS-10	Closed safe geometry heating or cooling loop with monitoring and alarm	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.4.8
CS-11	Simple overflow to normally empty safe geometry tank with level alarm	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2
CS-12	Condensing pot or seal pot in ventilation vent line	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2
CS-13	Simple overflow to normally empty safe geometry floor with level alarm in the hot cell containment boundary	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2

Table 1-8. Summary of Items Relied on for Safety Identified by Accident Analyses (3 pages)

IROFS designator	Descriptor	ESF	AC	Construction Permit Application crosswalk (primary references)
CS-14	Active discharge monitoring and isolation	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2
CS-15	Independent active discharge monitoring and isolation	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2
CS-16	Sampling and analysis of uranium mass or concentration prior to discharge or disposal		✓	Chapter 13.0, Section 13.2.7.2
CS-17	Independent sampling/analysis of uranium concentration prior to discharge or disposal		✓	Chapter 13.0, Section 13.2.7.2
CS-18	Backflow prevention device	✓		Chapter 6.0, Sections 6.2.1.7 and 6.3.1.2 Chapter 13.0, Section 13.2.4.8
CS-19	Safe-geometry day tanks	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.4.8
CS-20	Evaporator or concentrator condensate monitoring	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.4.8
CS-21	Visual inspection of accessible surfaces for foreign debris		✓	Chapter 13.0, Section 13.2.7.2
CS-22	Gram estimator survey of accessible surfaces for gamma activity		✓	Chapter 13.0, Section 13.2.7.2
CS-23	Nondestructive assay of items with inaccessible surfaces		✓	Chapter 13.0, Section 13.2.7.2
CS-24	Independent nondestructive assay of items with inaccessible surfaces		✓	Chapter 13.0, Section 13.2.7.2
CS-25	Target housing weighing prior to disposal		✓	Chapter 13.0, Section 13.2.7.2
CS-26	Processing component safe volume confinement	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.7.2
CS-27	Closed heating or cooling loop with monitoring and alarm	✓		Chapter 6.0, Section 6.3.1.2 Chapter 13.0, Section 13.2.4.8
FS-01	Enhanced lift procedure		✓	Chapter 13.0, Section 13.2.2.8, 13.2.7.1
FS-02	Overhead cranes		✓	Chapter 13.0, Section 13.2.7.3
FS-03	Process vessel emergency purge system	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.7.3
FS-04	Irradiated target cask lifting fixture	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.6.5
FS-05	Exhaust stack height	✓		Chapter 6.0, Section 6.2.1.7 Chapter 13.0, Section 13.2.7.3

[a] Reserved – IROFS designator currently unassigned.

AC = administrative control.
ESF = engineered safety feature.
IROFS = items relied on for safety.

1.3 GENERAL DESCRIPTION OF THE FACILITY

1.3.1 Location and Characteristics of the Site

Site location – The proposed 3.0 hectare (ha) (7.4-acre) site of the RPF is situated in Boone County, within the University of Missouri (MU) Discovery Ridge Research Park (Discovery Ridge) in Columbia, Missouri, north of Discovery Ridge Drive. The site is situated in central Missouri approximately 201 kilometers (km) (125 miles [mi]) east of Kansas City and 201 km (125 mi) west of St. Louis. The site is 7.2 km (4.5 mi) south of United States (U.S.) Interstate Highway 70 just to the north of U.S. Highway 63. The Missouri River lies 15.3 km (9.5 mi) to the west of the site. Figure 1-7 (on page 1-19) provides the 8 km (5-mi) radius from the center of the facility and shows highways, rivers, and other local bodies of water.

Figure 1-4 shows the layout of the NWMI site, including the RPF.

Figure 1-4. Radioisotope Production Facility Site Layout

Figure 1-5 provides a building model view of the RPF. The building will be divided into material accountability areas that are regulated by 10 CFR 50 and 10 CFR 70, as shown in Figure 1-6. The target fabrication area will be governed by 10 CFR 70, and the remainder of the production areas (irradiated target receipt bay, hot cells, waste management, laboratory, and utilities) will be governed by 10 CFR 50. The administration and support area will provide the main personnel access to the RPF and include personnel support areas such as access control, change rooms, and office spaces.

The first level (excluding the tank pit area) and second levels of the RPF are currently estimated to contain approximately 4,282 square meters (m^2) (46,088 square feet [ft^2]) and 1,569 m^2 (16,884 ft^2) of floor space, respectively. The processing hot cell and waste management temporary storage floor space area is approximately 544 m^2 (5,857 ft^2). The maximum height of the building is 19.8 meter (m) (65 ft), with a maximum stack height of 22.9 m (75 ft). The depth of the processing hot cell below-grade, without footers, is 4.6 m (15 ft) of enclosure height in rooms containing process equipment. The site is enclosed by perimeter fencing to satisfy safeguards and security and other regulatory requirements.

Figure 1-6 is first level general layout of the RPF and presents the seven major areas, including the target fabrication area, irradiated target receipt area, tank hot cell area, laboratory area, waste management area, utility area, and administrative support area

Figure 1-5. Building Model of the Radioisotope Production Facility

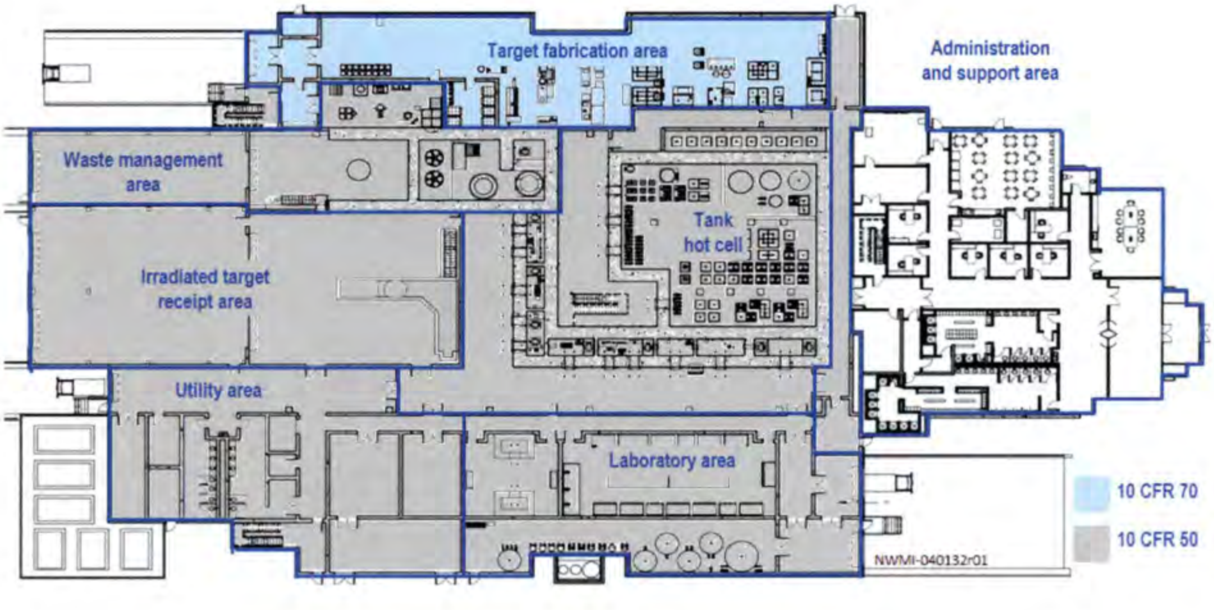

Figure 1-6. General Layout of the Radioisotope Production Facility

Additional detailed facility information is provided in Chapter 4.0.

Population distribution – Estimates and projections of resident and transient populations around the proposed project site are divided into five distance bands—concentric circles at 0-1 km (0-0.6 mi), 1-2 km (0.6-1.2 mi), 2-4 km (1.2-2.5 mi), 4-6 km (2.5-3.7 mi), and 6-8 km (3.7-5.0 mi) from the center point of the RPF—and 16 directional sectors (with each direction sector centered on one of the 16 compass points). For each segment formed by the distance bands and directional sectors, the resident population was estimated using U.S. Census Bureau 2010 census data (USCB, 2010). The extrapolated population data for 2014 is also shown on Figure 1-7.

The permanent residences nearest to the proposed RPF site were identified through an examination of aerial photographs and geographic information system data files using ArcGIS 10.1 (ESRI, 2011). There are two permanent residences located approximately 0.48 km (0.3 mi) from the center point, one to the south and the other to the northeast. These two houses are the closest residences to the center point of the safety-related area.

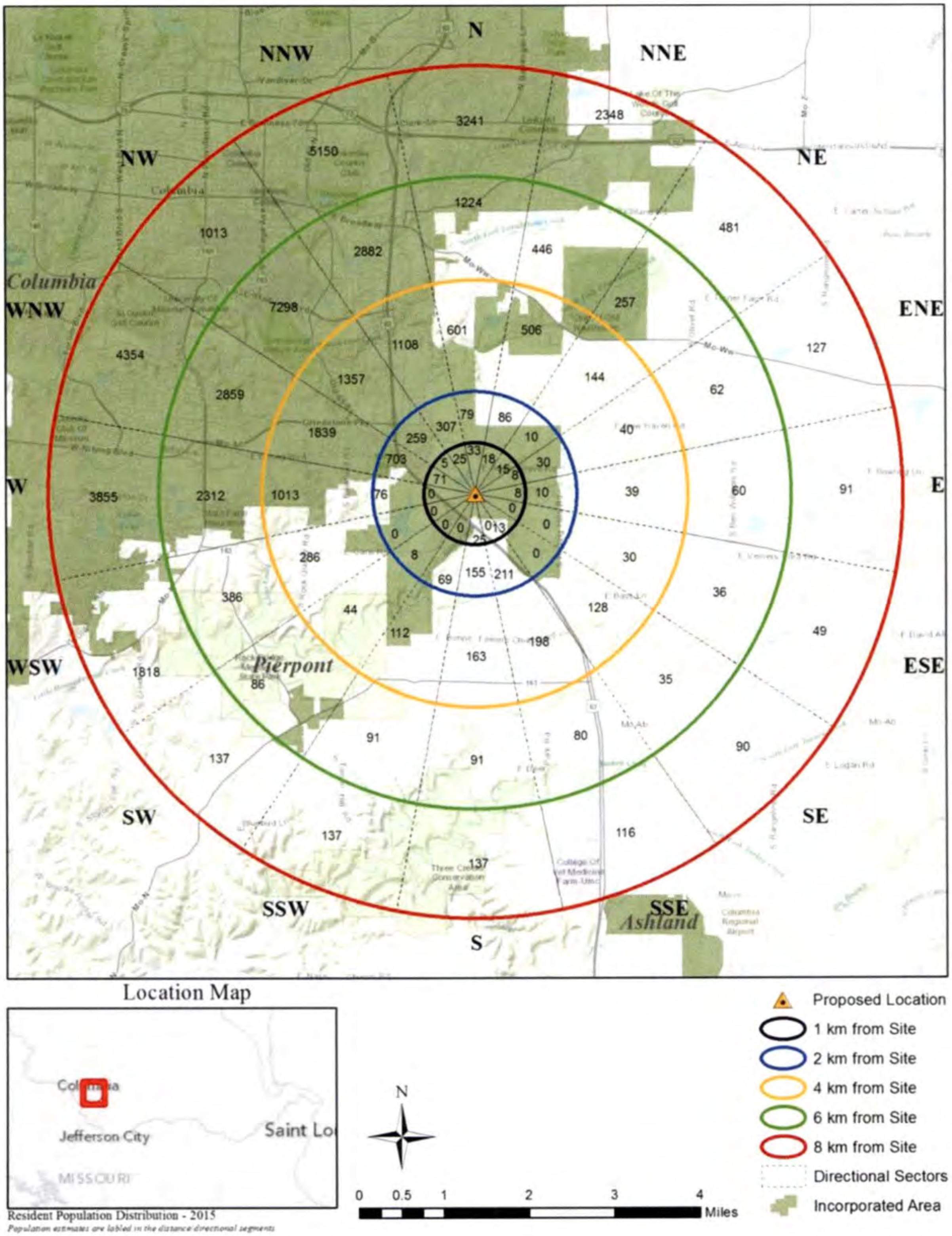

Figure 1-7. 8 km (5-mi) Radius from the Center of the Facility and Resident Population Distribution – 2015

Nearby industrial, transportation, and military facilities – An investigation of industrial, transportation and military facilities within 8 km (5 mi) of the proposed site was performed. The U.S. Environmental Protection Agency's Envirofacts Database was initially used to identify potential facilities within 8 km (5 mi). The Missouri Emergency Management Agency supplied Tier II chemical inventory reports for all of the facilities in Boone County. The following facilities were identified for further evaluation.

Industrial Facilities

- Analytical Bio Chemistry Laboratories, Inc.
- Radil Discovery Ridge
- Gates Power Transmissions Materials Center
- MU South Farm
- MU Woman's and Children's Hospital
- Ryder Transportation
- Truegreen
- Schwan's Home Service
- Petro Mart #44

Pipelines

- Southern Star Central Gas – Natural Gas Transmission Pipeline
- Magellan Pipeline Company – Non-HLV product Hazardous Pipeline
- Magellan Pipeline Company – Liquid Hazardous Pipeline
- Ameren Natural Gas – Transmission Pipeline #1
- Ameren Natural Gas – Transmission Pipeline #2

Fuel Storage Facilities

- Magellan Pipeline Company – Breakout Tank

Transportation Routes/Facilities

- Air
  - University of Missouri Heliport
  - Boone Hospital Center Heliport
- Land
  - U.S. Highway 63
  - U.S. Interstate 70
  - State Route 163
  - State Route 740
  - State Route 763
- Waterways – None
- Railroads – COLT Transload

Military Bases

- None

Mining and Quarrying Operations

- None

Air Traffic – There are three airports and three helicopter ports located within 16 km (10 mi) of the proposed RPF site. The three airports include:

- Columbia Regional Airport (COU) (public) located approximately 10.4 km (6.5 mi) south of the RPF site
- Cedar Creek Airport (private) located approximately 10.6 km (6.6 mi) northeast of the RPF site
- Sugar Branch Airport (private) located approximately 15.6 km (9.7 mi) northwest of the RPF site

The nearest airport to the RPF is COU, which is used by commercial and privately owned aircraft. The airport is situated on approximately 532 ha (1,314 acres) and is owned and operated by the City of Columbia. This airport is the only public use airport located in Boone County, Missouri, for which records are kept. For January through December 2016, the airport had 21,894 (22,439, including overflights) aircraft operations (Parks, 2017), including:

- 67.6 percent general aviation
- 17.7 percent air taxi
- 9.3 percent military
- 4.8 percent air carrier

Cedar Creek airport is a private, turf landing strip approximately 10.6 km (6.6 mi) northeast of the RPF site. The facility houses two private single engine aircraft. The specific number of flights to and from the facility is not available.

The Sugar Branch airport is a private, turf landing strip approximately 15.6 km (9.7 mi) northwest of the RPF site. The facility houses one single engine aircraft. The specific number of flights to and from the facility are not available.

Based on the results shown above and NUREG-0800, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*, COU needs to be further evaluated. The guidance also requires that special consideration be given to facilities sited within the trajectory of a runway of any airport. The RPF site is not located within a trajectory of a runway of the airport.

The impact frequency for each aircraft category for COU is as follows:

- General aviation 1.78E-07
- Commercial air carrier 1.61E-11
- Air taxis 3.27E-11
- Military large 1.66E-08

Two helicopter ports are located within 16 km (10 mi) of the RPF site that support hospital operations. For calendar year 2016 (January through December), the heliports have a total of 654 flights annually, as follows:

- University of Missouri Hospital and Clinics located 6 km (3.7 mi) northwest – 308 flights (Jones, 2017)
- Boone Hospital Center heliport located 6.3 km (3.9 mi) northwest – 346 flights (Eidson, 2017)

Because the heliports are closer than 8 km (5 mi) to the RPF site, the frequency of an aircraft crashing into the site needs was evaluated. NUREG-0800, Section 3.5.1.6, "Aircraft Hazards," provides a methodology for determining the probability of an aircraft crash into a facility from airways. However, the approach requires knowledge of the number of flights per year along the airway. Because this information is not available for the flight paths near the RPF, DOE-STD-3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, was used to determine the frequency of crashes.

The effective area for an aircraft was determined by two components: the aircraft crashing into the facility either by skidding or by flying directly into it. The effective area was calculated based on an aircraft skidding or flying into the facility in the direction that produces the largest area (i.e., crashing in a direction perpendicular to the largest diagonal of the building). The calculated crash impact frequency from the heliport is less than the requirement of NUREG-0800 of being within an order of magnitude of 10^{-7} per year. Therefore, no further analysis is required.

There are no military airports or training routes located within 16 km (10 mi) of the RPF site.

Meteorology – The RPF location places it in the Humid Continental-Warm Summer climatic zone. This type of climate has a characteristic long, warm summer with moderate relative humidity. The winters are cool to cold and mark a period of lower precipitation than during the remainder of the year. Because of its geographical location far inland, the region is subject to significant seasonal and daily temperature variations. Air masses moving over the state during the year include cold continental polar air from Canada, warm and humid maritime tropical air from the Gulf of Mexico and the Caribbean Sea, and dry eastward flowing air masses from the Rocky Mountains located to the west. Prolonged periods of extreme hot or cold temperatures are unusual (MU, 2006).

Spring, summer, and early fall precipitation occurs in the form of rain and thunderstorms. Severe thunderstorms typically occur during the period from mid- to late-spring through early summer. Hail may be expected as a product of these storms. Wind speeds of up to 97 km/hr (60 mi/hr) or more may be experienced once or twice a year during a severe thunderstorm (MU, 2006).

NUREG-1537, Part 1, Section 2.3.1, states that the snow load should be based on the 100-year return period snow accumulation. For MU facilities, the 2012 International Building Code (IBC) (IBC, 2012) has been levied as the required building code. The ground snow load is 20 pounds (lb)/ft^2. To modify the snow load to be based on a 100-year return period, an importance factor of 1.2 is applied to the load determined using the nominal snow load (ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, Section C7.3.3). The nominal ice thickness is 2.54 centimeters (cm) (1 inch [in.]) concurrent with a 64.4 km/hr (40-mi/hr), 3-second (sec) wind gust. To modify the ice load based on a 100-year return period, an importance factor of 1.25 is applied to the load determined using the nominal ice load (ASCE 7, Section C10.4.4).

Wind – Extreme wind speeds are uncommon in central Missouri. Wind that does occur is usually caused by pressure gradients and temperature contrasts present in the mid-latitude cyclones that pass through the state. These cyclones may spawn storms that produce high winds from gust fronts, microbursts, and tornadoes. Non-storm-related extreme winds are rare. Occasionally, cold high-pressure air filling in behind a front will cause high wind, especially in the winter when temperature contrasts are large.

Figure 1-8 shows the wind patterns recorded at the Remote Automatic Weather Station in Columbia. Wind roses show that the prevailing surface wind direction is from the south, with a total average speed of 14.16 km/hr (8.8 mi/hr). The average frequency of higher speed winds falls into the 24 to 40 km/hr (15 to 25-mi/hr) range.

NUREG-1537, Part 1, Section 2.3.1, states that the wind load should be based on the 100-year return period wind speed. For MU facilities, IBC (2012) has been levied as the required building code. The basic wind speed for Category III and IV facilities is 193.1 km/hr (120 mi/hr). An evaluation of the effective return period for the basic wind speeds for Category III and IV facilities determined that the effective return period is 1,700 years (3 percent in 50 years, or 5.7 percent in 100 years) (ASCE 7, Section C26.5.1). Note that an event with a 100-year return period has a 63 percent chance of occurring at least once in a 100-year period.

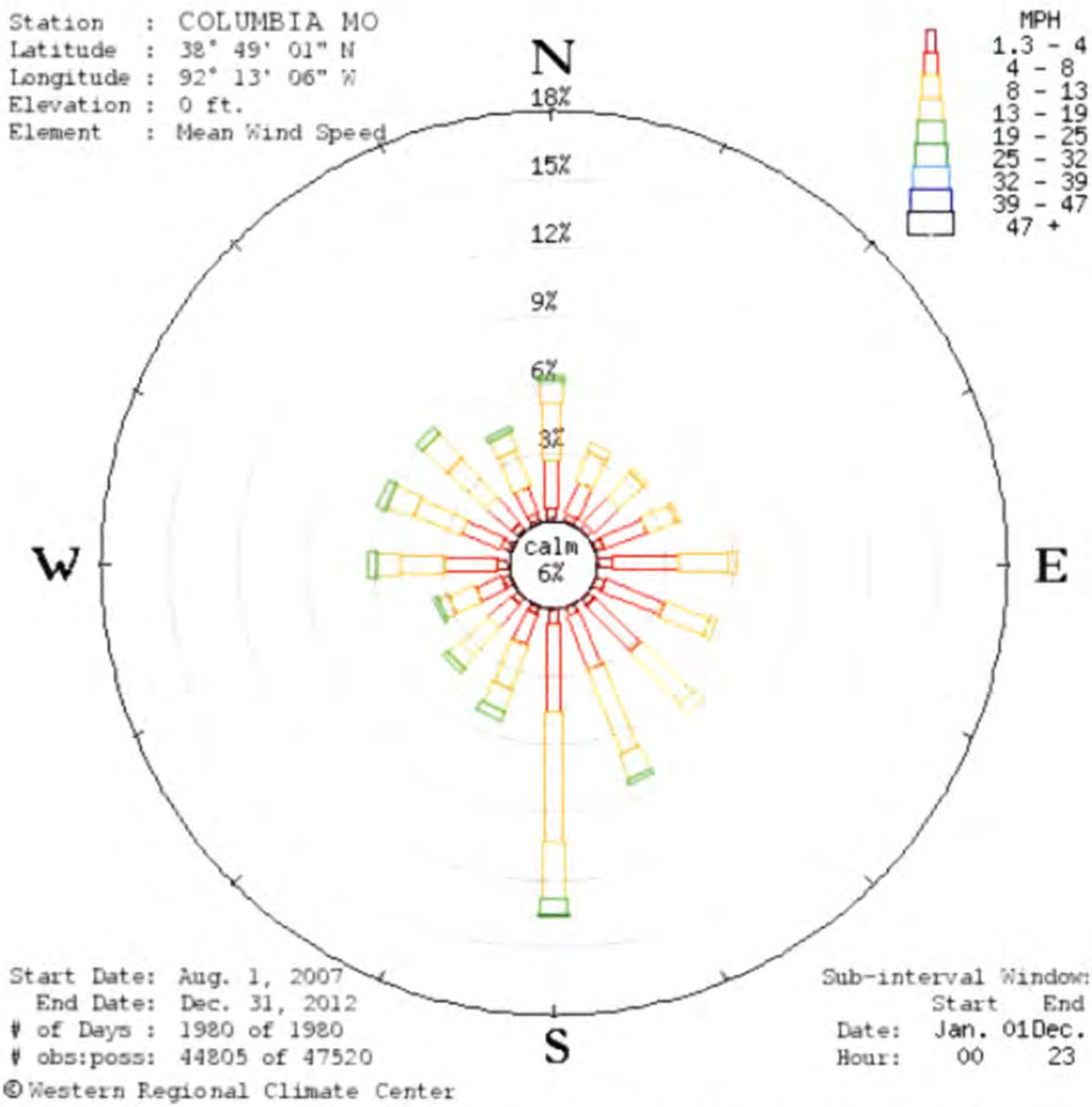

Figure 1-8. Wind Rose from Automatic Weather Station, Columbia, Missouri, 2007-2012 (Western Regional Climate Center)

Tornado – The heartland of the country has the distinction of also being known as "tornado alley," a non-meteorological term that references the area where 90 percent of tornadoes have occurred as a result of the mixing of cold, dry air from Canada and the Rocky Mountains, with warm, moist air from the Gulf of Mexico and hot, dry air from the Sonoran Desert. This area typically exhibits atmospheric instability, heavy precipitation, and many intense thunderstorms.

Tornados are extreme wind speed events that are classified according to the Enhanced Fujita Tornado Intensity Scale (EF scale). The scale matches wind speeds to the severity of damaged caused by a tornado. The process involves determining the degree of damage according to a predefined damage scale of 28 indicators. The observed damage is associated with estimated wind speeds during the storm, and an EF scale number is assigned. Measuring tornadoes from EF-1 to EF-5, the scale uses more specific structural damage guidelines than the original Fujita scale (F scale), which was established in 1971. Table 1-9 shows the F and EF scales.

Table 1-9. Fujita Scale and Enhanced Fujita Scales Used to Determine Tornado Intensity

	F scale					EF scale	
	Fastest 1/4-mi		3-sec gust			3-sec gust	
F number	(km/hr)	(mi/hr)	(km/hr)	(mi/hr)	EF number	(km/hr)	(mi/hr)
0	64 -116	40–72	72-126	45–78	0	105-137	65-85
1	117 – 180	73–112	127-188	79–117	1	138-177	86–110
2	182- 253	113–157	189-259	118–161	2	178-217	111–135
3	254- 333	158–207	260-336	162–209	3	218-265	136–165
4	334- 418	208–260	337-420	210–261	4	266-322	166–200
5	419 – 512	261–318	421-510	262–317	5	Over 322	Over 200

EF scale = enhanced Fujita tornado intensity scale.
F scale = Fujita tornado intensity scale.

Flooding – The site is located outside of the 500-year flood plain. The nearest Federal Emergency Management Agency (FEMA) flood zone A is along Gans Creek, located to the southeast of the site. The elevation of this zone is 242 m (795 ft). The RPF site elevation is 248 m (815 ft). There are no water impoundments or dams upstream of the RPF site on Gans Creek that could affect the facility.

There are also two ponds located near the RPF site within Discovery Ridge. These ponds include the 7.9 ha (19.6-acre) common grounds stormwater management pond located to the northwest of the site. The top of the dam for this pond is 246 m (807 ft), with the spillway at 245 m (804 ft). The second pond, currently approximately 4 ha (10 acres), is located to the northeast of the site. The elevation of the dam is approximately 244 m (801 ft). Failure of either of these two ponds would not likely affect the RPF because the elevation of the dams is lower than the elevation of the RPF.

Seismic – The most significant seismological feature in Missouri is the New Madrid Seismic Zone (NMSZ), located in the southeastern corner of the state and extending into parts of the contiguous states of Arkansas, Tennessee, Kentucky, and Illinois. The NMSZ is the most seismically active region in the U.S. east of the Rocky Mountains and is located approximately 483 km (300 mi) southeast of the proposed RPF site. During the winter of 1811–1812, the NMSZ was the location of some of the highest intensity seismic events ever noted in U.S. history. Hundreds of aftershocks, some severely damaging, continued for years.

Records show that since 1900, moderately damaging earthquakes have struck the NMSZ every few decades. Prehistoric earthquakes similar in size to those of 1811–1812 occurred in the middle 1400s and around 900 A.D. Strong, damaging earthquakes struck the southwestern end of the NMSZ near Marked Tree, Arkansas, in 1843 (magnitude 6.0), and the northeastern end near Charleston, Missouri, in 1895 (magnitude 6.6) (USGS, 2011a).

The NMSZ is made up of reactivated faults that formed when what is now North America began to split or rift apart approximately 500 million years ago. The resulting rift system died out before an ocean basin was formed, but a deep zone of weakness was created, referred to as the Reelfoot rift (USGS, 2011b). This fault system extends 241 km (150 mi) southward from Cairo, Illinois, through New Madrid and Caruthersville, Missouri, down through Blytheville, Arkansas, to Marked Tree, Arkansas. The Reelfoot rift dips into Kentucky near Fulton and into Tennessee near Reelfoot Lake, extending southeast into Dyersburg, Tennessee. The rift then crosses five state lines and crosses the Mississippi River in at least three places. The fault system is buried beneath as much as 8 km (5 mi) of sediment for much of the fault length and typically cannot be seen at the surface (USGS, 2011b).

Four of the largest faults are recognized as alignments of abundant small earthquakes, and movements along two of these faults dammed rivers and created lakes during the earthquakes of 1811–1812. A few more deeply buried faults were detected during oil and gas exploration, and a few small faults are known from geologic mapping (USGS, 2011b).

The remainder of the state, including the proposed RPF site located in central Missouri, is typical of the stable midcontinent U.S.

Earthquakes occur on faults within bedrock, usually several miles deep. According to the U.S. Geological Survey (USGS), earthquakes in the central and eastern U.S. typically are felt over a much broader region than in the western U.S. East of the Rocky Mountains, an earthquake can be felt over an area ten times larger than a similar magnitude earthquake on the west coast.

According to information from Missouri's State Emergency Management Agency Earthquake Program, some of the earthquakes measure at least 7.6 in magnitude and five of them measured 8.0 or greater. The 1811–1812 series changed the course of the Missouri River, and some shocks were felt as far away as Washington D.C. and Boston (MMRPC, 2010). The NMSZ has experienced numerous earthquakes since the 1811–1812 series, and at least 35 aftershocks of intensity V or greater that have been recorded in the state of Missouri since 1811. Numerous earthquakes originating outside of the state's boundaries have also affected Missouri.

In 2002, the USGS released the following projected hazards for Boone County, if an earthquake occurred along the NMSZ in the following 50 years (MMRPC, 2010):

- 25 to 40 percent chance of a magnitude 6.0 and greater earthquake
- 7 to 10 percent chance of a magnitude 7.5 to 8.0 earthquake

According to the USGS, Boone County is one of the 47 counties in Missouri that would be severely impacted by a 7.6 magnitude earthquake with an epicenter on or near the NMSZ.

According to the *Boone County Hazard Mitigation Plan for 2010* (MMRPC, 2010), the Missouri State Emergency Management Agency has made projections of the highest earthquake intensities that would be experienced throughout the state of Missouri if various magnitude earthquakes occur along the NMSZ as measured by the Modified Mercalli Intensity (MMI) scale. The pertinent information for Boone County is summarized in Table 1-10.

Table 1-10. Projected Earthquake Hazards for Boone County

Magnitude at NMSZ	Probability of occurrence (2002–2052)	Intensity in Boone County (MMI)	Expected damage
6.7	25–40%	VI, strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
7.6	7–10%	VII, very strong	Difficult to stand; significant damage to poorly or badly designed buildings, adobe houses, old walls, spires, and other; damage would be slight to moderate in well-built buildings; numerous broken windows; weak chimneys break at roof lines; cornices from towers and high buildings fall; loose bricks fall from buildings; heavy furniture is overturned and damaged; and some sand and gravel stream banks cave in.

Source: MMRPC, 2010, *Boone County Hazard Mitigation Plan*, www.mmrpc.org/the-region/boone-county, Mid-Missouri Regional Planning Commission, State of Missouri Emergency Management Agency, Ashland, Missouri, July 15, 2010.

MMI = Modified Mercalli Intensity.
NMSZ = New Madrid Seismic Zone.

Additional detailed site information is provided in Chapter 2.0, "Site Characteristics."

1.3.2 Principal Design Criteria, Operating Characteristics, and Safety Systems

NWMI's RPF design is based on applicable standards, guides, codes, and criteria and provides reasonable assurance that the RPF SSCs, including electromechanical systems:

- Are built and will function as designed and required by the analyses in Chapter 13.0, "Accident Analysis"
- Ensure acceptable protection of the public health and safety and environment from radiological risks (e.g., radioactive materials, exposure) resulting from operations
- Protect against potential hydrological (water) damage
- Protect against seismic damage
- Provide surveillance activities and technical specifications required to respond to or mitigate consequences of seismic damage
- Have technical specifications developed to ensure that safety-related functions of electromechanical systems and components will be operable and protect the health and safety of workers, the public, and environment

Defense-in-depth is a design philosophy, applied from the outset and through completion of the design that is based on providing successive levels of protection such that health and safety are not wholly dependent on any single element of the design, construction, maintenance, or operation of the facility. The net effect of incorporating defense-in-depth practices is a conservatively designed facility and systems that exhibit higher tolerances to failures and external challenges. The risk insights obtained through performance of accident analysis can then be used to supplement the final design by focusing attention on the prevention and mitigation of the higher risk potential accidents.

The design basis and facility SSCs for the RPF are based on defense-in-depth practices. Defense-in-depth is a design philosophy, applied from the beginning and through completion of the design, which is based on providing successive levels of protection such that health and safety are not wholly dependent on any single element of the design, construction, maintenance, or operation of the facility. The net effect of incorporating defense-in-depth practices is a conservatively designed facility and systems that exhibit a higher tolerance to failures and external challenges. The risk insights obtained through the performance of accident analysis can then be used to supplement the final design by focusing attention on the prevention and mitigation of the higher risk potential accidents.

1.3.2.1 Principal Design Criteria

NWMI addresses the following baseline design criteria for the RPF.

- **Quality standards and records** – Design is being developed and implemented in accordance with management measures to provide adequate assurance that IROFS will be available and reliable to perform the intended functions when needed. Appropriate records of these items must be maintained by or under the control of the licensee throughout the life of the facility.
- **Natural phenomena hazards** – Design will provide for adequate protection against natural phenomena with consideration of the most severe documented historical events for the site.
- **Fire protection** – Design will provide for adequate protection against fires and explosions.
- **Environmental and dynamic effects** – Design will provide for adequate protection from environmental conditions and dynamic effects associated with normal operations, maintenance, testing, and postulated accidents that could lead to loss of safety functions.
- **Chemical protection** – Design will provide for adequate protection against chemical risks produced from licensed material, facility conditions that affect the safety of licensed material, and hazardous chemicals produced from licensed material.
- **Emergency capability** – Design will provide for emergency capability to maintain control of:
  - Material and hazardous chemicals produced from licensed material
  - Evacuation of on-site personnel
  - On-site emergency facilities and services that facilitate the use of available off-site services
- **Utility services** – Design will provide for continued operation of essential utility services.
- **Inspection, testing, and maintenance** – Design of IROFS will provide for adequate inspection, testing, and maintenance to ensure availability and reliability to perform intended function when needed.
- **Criticality control** – Design will provide for criticality control, including adherence to the double-contingency principle.
- **Instrumentation and controls** – Design will provide for inclusion of instrumentation and control (I&C) systems to monitor and control the behavior of IROFS.
- Facility and system design and facility layout will be based on defense-in-depth practices. Design will incorporate, to the extent practicable:
  - Preference for the selection of engineered controls over administrative controls to increase overall system reliability
  - Features that enhance safety by reducing challenges to IROFS

The principal design criteria for a production facility establish the necessary design, fabrication, construction, testing, and performance requirements for SSCs important to safety (i.e., those that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of workers and the public). The systems associated with the RPF are identified below, and the associated IROFS are identified in Chapter 6.0, "Engineered Safety Features," and Chapter 13.0. Requirements are derived from:

- Code of Federal Regulations
- U.S. Nuclear Regulatory Commission
- Federal regulations, guidelines, and standards
- Local government regulations and requirements
- Discovery Ridge covenants
- MU System requirements
- Other codes and standards

Table 1-11 lists the RPF systems, and identifies the RPF material accountability area and the Construction Permit Application reference chapter that provides the associated detailed system descriptions.

Table 1-11. List of System and Associated Systems and Construction Permit Application Crosswalk (2 pages)

Primary structure and associated systems	Construction Permit Application reference (primary references)
Radioisotope Production Facility (RPF – primary structure)	
10 CFR 70[a]	
Target fabrication	Chapter 4.0, Sections 4.1.3.1 and 4.4
10 CFR 50[b]	
Target receipt and disassembly	Chapter 4.0, Section 4.1.3.2, 4.3.2, and 4.3.3
Target dissolution	Chapter 4.0, Sections 4.1.3.3 and 4.3.4
Molybdenum recovery and purification	Chapter 4.0, Sections 4.1.3.4 and 4.3.5
Uranium recovery and recycle	Chapter 4.0, Sections 4.1.3.5 and 4.3.6
Waste handling	Chapter 4.0, Section 4.1.3.6; Chapter 9.0, Section 9.7.2
Criticality accident alarm	Chapter 6.0, Section 6.3.3.1; Chapter 7.0, Section 7.3.7
Radiation monitoring	Chapter 7.0, Section 7.6; Chapter 11.0, Section 11.1.4
Normal electrical power	Chapter 8.0, Section 8.1
Standby electrical power	Chapter 8.0, Section 8.2
Process vessel ventilation	Chapter 9.0, Section 9.1
Facility ventilation	Chapter 9.0, Section 9.1
Fire protection	Chapter 9.0, Section 9.3
Plant and instrument air	Chapter 9.0, Section 9.7.1
Emergency purge gas	Chapter 9.0, Section 9.7.1
Gas supply	Chapter 9.0, Section 9.7.1
Process chilled water	Chapter 9.0, Section 9.7.1
Facility chilled water	Chapter 9.0, Section 9.7.1
Facility heated water	Chapter 9.0, Section 9.7.1
Process steam	Chapter 9.0, Section 9.7.1
Demineralized water	Chapter 9.0, Section 9.7.1
Chemical supply	Chapter 9.0, Section 9.7.4

Table 1-11. List of System and Associated Systems and Construction Permit Application Crosswalk (2 pages)

Primary structure and associated systems	Construction Permit Application reference (primary references)
Biological shield	Chapter 4.0, Section 4.2
Facility process control	Chapter 7.0, Section 7.2.3

[a] 10 CFR 70, "Domestic Licensing of Special Nuclear Material," *Code of Federal Regulations*, Office of the Federal Register, as amended.

[b] 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," *Code of Federal Regulations*, Office of the Federal Register, as amended.

Detailed design standards and codes for the RPF SSCs are listed in Chapter 3.0, "Design of Structures, Systems, and Components."

1.3.2.2 Operating Characteristics

A flow diagram of the primary process to be performed at the RPF is provided in Figure 1-9. The primary purpose of these RPF operations is to provide ^{99}Mo product in a safe, economic, and environmentally protective manner.

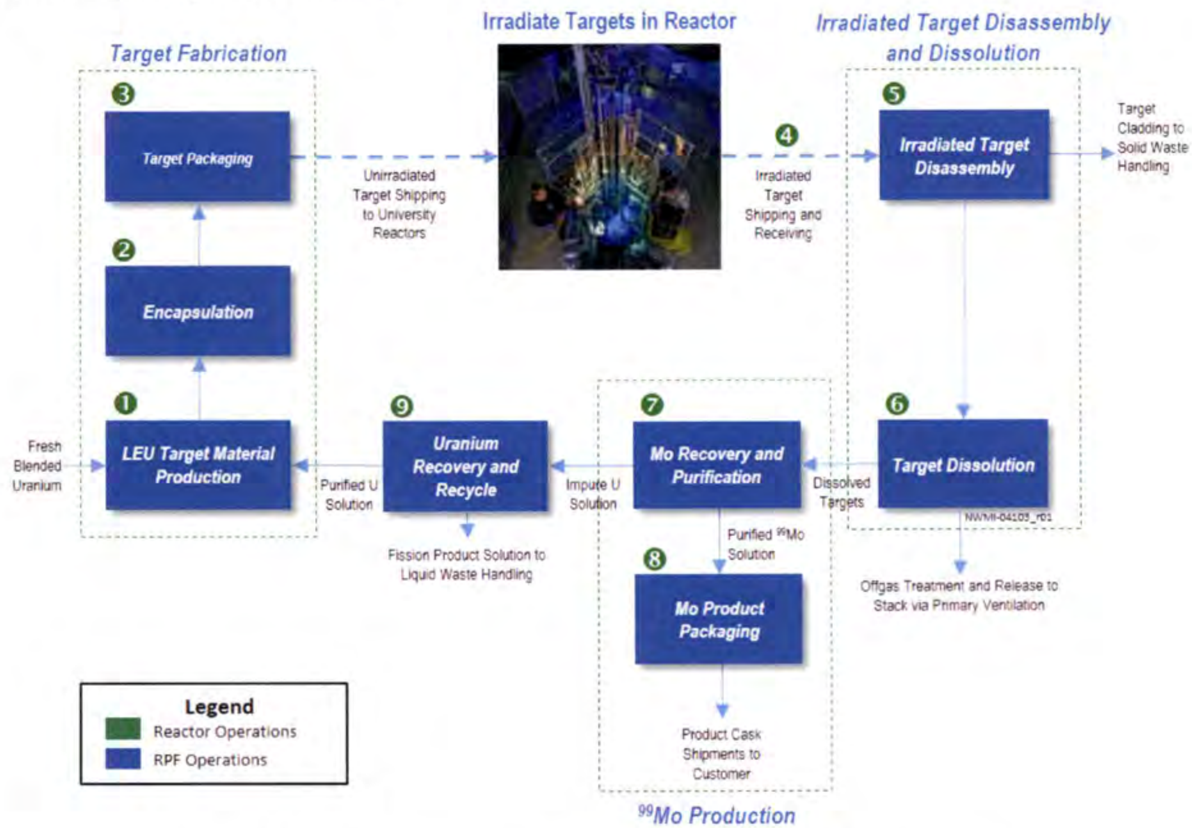

Figure 1-9. Radioisotope Production Facility Block Flow Diagram

Facility operation has the following general process steps (which correspond with Figure 1-9).

Target Fabrication

1. LEU target material is fabricated using a combination of fresh LEU and recycled uranium.
2. Target material is encapsulated using metal cladding to contain the LEU and fission products produced during irradiation.
3. Fabricated targets are packaged and shipped to university reactors for irradiation.

Target Receipt, Disassembly, and Dissolution

4. After irradiation, targets are shipped back to the RPF.
5. Irradiated targets are disassembled and metal cladding is removed.
6. Targets are then dissolved into a solution for processing.

Molybdenum Recovery and Purification

7. Dissolved LEU solution is processed to recover and purify ^{99}Mo.
8. Purified ^{99}Mo is packaged in certified shipping containers and shipped to a radiopharmaceutical distributor.

Uranium Recovery and Recycle

9. LEU solution is treated to recover uranium and remove trace contaminants and is recycled back to Step 1 to be made into new targets via the target fabrication system.

The RPF operating and process characteristics are described in more detail in Chapter 4.0.

1.3.2.2.1 Target Fabrication Process Description

The target fabrication process will center on the production of LEU target material that is generated through an [Proprietary Information]; the LEU target material will subsequently be loaded into aluminum target elements. The LEU feed for the [Proprietary Information] will be chilled UN and consist of a combination of fresh LEU, recovered LEU, and LEU recovered from the processing of irradiated targets. [Proprietary Information].

The aluminum target components will be cleaned, and then a target subassembly will be welded and loaded with LEU target material. This target subassembly will subsequently be filled with a helium or air cover gas and sealed by welding on the remaining hardware end cap. The completed targets will be inspected and quality checked using a process similar to that performed for commercial nuclear fuel. The targets will then be shipped back to the reactor sites for irradiation.

The target fabrication process will begin with the receipt of fresh uranium from DOE, target hardware, and chemicals associated with LEU target material production and target assembly. The target fabrication process will center on the production of LEU target material that is generated through [Proprietary Information], which will subsequently be loaded into aluminum target elements. The uranium feed for the [Proprietary Information] acid deficient uranyl nitrate (ADUN) solution. This feed will consist of a combination of fresh uranium, off-specification uranium recovered from target fabrication processes, and uranium recovered from the processing of irradiated targets. The fresh uranium, enriched to 19.75 weight percent (wt%) uranium-235 (^{235}U), will be received as uranium metal and dissolved in nitric acid. The reactant for the [Proprietary Information] will be a chilled mixture of hexamethylenetetramine (HMTA) and urea, and the uranium [Proprietary Information]. The HMTA will decompose on contact with the heated silicone oil, releasing ammonia for [Proprietary Information]. The uranium-gel particles will then be filtered, washed, dried, calcined, and reduced to high-density LEU target material.

The target hardware components will be cleaned, and a target subassembly will be welded and loaded [Proprietary Information] by means of a [Proprietary Information]. This target subassembly will subsequently be filled with helium or air cover gas and sealed by welding on the remaining hardware end cap. The completed targets will then be inspected and quality checked.

1.3.2.2.2 Target Disassembly and Dissolution Process Description

The target receipt and disassembly process will be operated in a batch mode, starting with receipt of a batch of targets inside a shipping cask. The targets will be disassembled one at a time, and the irradiated LEU target material will be transferred to a dissolver.

The target dissolution hot cells operations will start with the transfer of the collection containers containing irradiated LEU target material from the target disassembly hot cells. A dissolver basket will then be filled with the contents of the collection container. Multiple containers may be loaded into the dissolver basket. The dissolver Basket will be lowered into place in the dissolver assembly via the open valve. After loading the dissolver basket into the dissolver assembly, the valves will be closed in preparation for the start of dissolution. The LEU target material will be dissolved in hot nitric acid.

The offgas containing the fission product gases will go through a series of cleanup columns. The nitrogen oxide (NO_x) will be removed by a reflux condenser and several NO_x absorbers, the fission product gases (noble and iodine) will be captured on absorbers, and the remaining gas will be filtered and discharged into the process ventilation header. The dissolver solution will be diluted, cooled, filtered, and pumped to the ^{99}Mo system feed tank. Only one of the two dissolvers is planned to be actively dissolving LEU target material at a time.

1.3.2.2.3 Molybdenum Recovery and Purification Process Description

Acidified dissolver solution from the target dissolution operation will be processed by the Mo recovery and purification system to recover the ^{99}Mo. The Mo recovery and separation process primarily consists of a series of chemical adjustments and ion exchange (IX) columns to remove unwanted isotopes from the Mo product solution. Product solution will be sampled to verify compliance with acceptance criteria after a final chemical adjustment. The product solution will then be placed into shipping containers that are sequentially loaded into shipping casks for transfer to the customer.

Waste solutions from the IX columns will contain the LEU present in the incoming dissolver solution and will be transferred to the LEU recovery system. The remaining waste solutions will be sent to low-or high-dose waste storage tanks.

1.3.2.2.4 Uranium Recycle and Recovery Process Description

The uranium recovery and recycle system will process aqueous LEU solutions generated in the Mo recovery and purification system to separate unwanted radioisotopes from uranium. Uranium will be separated from the unwanted radioisotopes using two cycles of IX. A concentrator will be provided for the uranium-bearing solution as part of each IX cycle to adjust the LEU solution uranium concentration. Vent gases from process vessels will be treated by the process vessel ventilation system prior to merging with the main facility ventilation system and release to the environment. Recycled uranium product will be an aqueous LEU solution that is transferred to the target fabrication system for use as a source to fabricate new reactor targets. Waste generated by the uranium recovery and recycle system operation will be transferred to the waste handling system for solidification, packaging, and shipping to a disposal site.

1.3.2.2.5 Liquid Waste Handling Process Description

The waste handling system is divided into three subsystems: (1) liquid waste system, (2) solid waste system, and (3) specialty waste system. The liquid waste disposal system will consist of a group of storage tanks for accumulating waste liquids and adjusting the waste composition. Liquid waste will be split into high-dose and low-dose streams by concentration. The high-dose fraction composition will be adjusted and mixed with adsorbent material. A portion of the low-dose fraction is expected to be suitable for recycle to selected systems as process water. Water that is not recycled will be adjusted and then mixed with an adsorbent material.

The solid waste disposal system will consist of an area for collection, size reduction, and staging of solid wastes. The solids will be placed in a 208 liter (L) (55-gallon [gal]) waste drum and encapsulated by adding a cement material to fill voids remaining within the drum. Encapsulated waste will be stored until the drums are loaded into a shipping cask and transported to a disposal site.

A specialty waste disposal system will address small quantities of unique wastes generated by other processes. The following are examples of these processes:

- A reclamation process to recycle organic solvent
- [Proprietary Information]
- Operation of a trichloroethylene (TCE) reclamation unit

The waste streams will be containerized, stabilized as appropriate, and shipped offsite for treatment and disposal.

1.3.2.3 Facility Ventilation System

The facility ventilation system, or RPF heating ventilation and air conditioning (HVAC) system, will be divided into four zones (Zone I, Zone II, Zone III, and Zone IV) with airflow directed from lowest to highest potential for contamination. The Zone I ventilation system will be the initial confinement barrier and will include gloveboxes, vessels, tanks, piping, hot cells, and the Zone I exhaust subsystem. The process vessel ventilation system exhausts to the Zone I exhaust subsystem, which will include two 100 percent capacity exhaust fans and filter trains for complete redundancy. Each filter train will consist of prefilters, two stages of high-efficiency particulate air (HEPA) filters, carbon adsorbers (for iodine removal), and isolation dampers. A separate stack with a monitoring and sampling system will be provided for the Zone I exhaust.

1.3.2.4 Biological Shield

The RPF biological shield will provide an integrated system of features that protects workers from the high-dose radiation generated during the radioisotope processing to recover ^{99}Mo. The primary function of the biological shield will be to reduce the radiation dose rates and accumulated doses in occupied areas to not exceed the limits of 10 CFR 20 and the guidelines of the facility ALARA (as low as reasonably achievable) program. The shielding and its components will withstand seismic and other concurrent loads, while maintaining containment and shielding during a design basis event.

1.3.3 Engineered Safety Features

ESFs are active or passive features designed to mitigate the consequences of accidents and to keep radiological exposures to workers, the public, and environment within acceptable values. The ESFs associated with confinement of the process radionuclides and hazardous chemicals for the RPF are summarized in Table 1-12, including the accidents mitigated, SSCs used to provide the ESFs, and references to subsequent sections providing a more detailed ESF description.

Confinement is a general ESF that is credited as being in place as part of the PHA described in Chapter 13.0. Additional IROFS associated with the confinement system were derived from the accident analyses in Chapter 13.0. The derived IROFS are also listed in Chapter 6.0, Table 6-1, with reference to more detailed descriptions in Section 6.2.1.

Table 1-12. Summary of Confinement Engineered Safety Features (2 pages)

Engineered safety feature	IROFS	Accident(s) mitigated	SSCs providing engineered safety features	Detailed description section
Confinement includes: • Hot cell liquid confinement boundary • Hot cell secondary confinement boundary • Hot cell shielding boundary	 RS-01 RS-03 RS-04	• Equipment malfunction and/or maintenance • Hazardous chemical spills	• Confinement enclosures including penetration seals • Zone I exhaust ventilation system, including ducting, filters, and exhaust stack • Zone I inlet ventilation system, including ducting, filters, and bubble-tight isolation dampers • Ventilation control system • Secondary iodine removal bed • Berms	6.2.1.1 through 6.2.1.6
Confinement IROFS Derived from Accident Analyses and Potential Technical Specifications				
Primary offgas relief system	RS-09	Dissolver offgas failure during dissolution operation	• Pressure relief device • Pressure relief tank	6.2.1.7.1
Active radiation monitoring and isolation of low-dose waste transfer	RS-10	Transfer of high-dose process liquid outside the hot cell shielding boundary	Radiation monitoring and isolation system for low-dose liquid transfers	6.2.1.7.2
Cask local ventilation during closure lid removal and docking preparations	RS-13	Target cladding leakage during shipment	Local capture ventilation system over closure lid during lid removal	6.2.1.7.3
Cask docking port enabler	RS-15	Cask not engaged in cask docking port prior to opening docking port door	Sensor system controlling cask docking port door operation	6.2.1.7.4
Process vessel emergency purge system	FS-03	SSC damage due to hydrogen deflagration or detonation	Backup bottled nitrogen gas supply	6.2.1.7.5
Irradiated target cask lifting fixture	FS-04	Dislodging the target cask shield plug while workers present during target unloading activities	• Cask lifting fixture design that prevents cask tipping • Cask lifting fixture design that prevents lift from toppling during a seismic event	6.2.1.7.6
Exhaust stack height	FS-05	• Equipment malfunction resulting in liquid spill or spray • Carbon bed fire	• Zone I exhaust stack	6.2.1.7.7

Table 1-12. Summary of Confinement Engineered Safety Features (2 pages)

Engineered safety feature	IROFS	Accident(s) mitigated	SSCs providing engineered safety features	Detailed description section
Double-wall piping	CS-09	Solution spill in facility area where spill containment berm is neither practical nor desirable for personnel chemical protection purposes	Double-wall piping for selected transfer lines	6.2.1.7.7
Backflow prevention devices Safe geometry day tanks	CS-18 CS-19	High worker exposure from backflow of high-dose solution	Backflow prevention devices located on process lines crossing the hot cell shielding boundary	6.2.1.7.9
Dissolver offgas iodine removal unit[a]	–	• Potential limiting control for operation • Primary iodine control system during normal operation	Dissolver offgas iodine removal units (DS-SB-600A/B/C)	6.2.1.8.2
Dissolver offgas primary adsorber[a]	–	• Potential limiting control for operation • Primary noble gas control system during normal operation	Dissolver offgas primary adsorber units (DS-SB-620A/B/C)	6.2.1.7.
Dissolver offgas vacuum receiver or vacuum pump[a]	–	• Potential limiting control for operation • Motive force for dissolver offgas	• Dissolver offgas vacuum receiver tanks (DS-TK-700A/B) • Dissolver offgas vacuum pumps (DS-P-710A/B)	6.2.1.8.3

[a] Examples of candidate technical specification rather than engineered safety feature.

IROFS = item relied on for safety. SSC = structures, systems, and components.

The current design approach does not anticipate requiring containment or an emergency cooling system as ESFs, as discussed in Chapter 6.0, Sections 6.2.2 and 6.2.3.

Nuclear criticality safety and associated controls are discussed in Chapter 6.0, Section 6.3. The currently defined criticality safety controls are derived from a combination of preliminary criticality safety evaluations and accident analyses, which are described in Chapter 13.0. The criticality safety analyses produce a set of features needed to satisfy the double-contingency requirements for nuclear criticality control. These features are evaluated by major systems within the RPF and listed by major system in Chapter 6.0, Section 6.3.1.1, Table 6-6 through Table 6-13. The accident analyses in Chapter 13.0 identify IROFS for the prevention of nuclear criticality, which are summarized in Chapter 6.0, Table 6-2, with reference to more detailed descriptions in Section 6.3.1.2.

Instrumentation and Control System

The RPF preliminary I&C configuration includes the SNM preparation and handling processes (e.g., target fabrication, and uranium recovery and recycle), radioisotope extraction and purification processes (e.g., target receipt and disassembly, target dissolution, Mo recovery and purification, and waste handling), process utility systems, criticality accident alarm system, and systems associated with radiation monitoring.

The SNM processes will be enclosed predominately by hot cells except for the target fabrication area. The facility process control (FPC) system will provide monitoring and control of the process systems within the RPF. In addition, the FPC system will provide monitoring of safety-related components within the RPF. The process strategy for the RPF involves the use of batch or semi-batch processes with relatively simple control steps.

The building management system (BMS) will monitor the RPF ventilation system and mechanical utility systems. The BMS primary functions will be to monitor the facility ventilation system and monitor and control (turn on and off) the mechanical utility systems.

ESF systems will operate on actuation of an alarm setpoint reached for a specific monitoring instrument/device. For redundancy, this will be in addition to the FPC system or BMS ability to actuate ESF as needed. Each ESF safety function will use hard-wired analog controls/interlocks to protect workers, the public, and environment. The ESF parameters and alarm functions will be integrated into and monitored by the FPC system or BMS.

The fire protection system will report the status of the fire protection equipment to the central alarm station and the RPF control room.

Cooling Water System

Cooling water systems are used to control the temperature of process solutions in the RPF from process activities and the heat load resulting from radioactive decay of the fission product inventory. The RPF is located at a separate site, independent from the reactors used to irradiate the targets. Therefore, the RPF cooling system does not influence operation of a reactor primary core cooling system.

Chilled water is used as the primary cooling fluid to process vessels. A central process chilled-water loop is used to cool three secondary loops: one large geometry secondary loop in the hot cell, one criticality-safe geometry secondary loop in the hot cell, and one criticality-safe geometry secondary loop in the target fabrication area. The central process chilled-water loop relies on air-cooled chillers, while the secondary loops are cooled by the central chilled-water system through plate-and-frame heat exchangers. Selected process demands require cooling at less than the freezing point of water. These demands are met with water-cooled refrigerant chiller packages, cooled by the secondary chilled water loops.

Electrical Power Systems

The RPF design uses high-quality, commercially available components and wiring in accordance with applicable code. Electrical power circuits will be isolated sufficiently to avoid electromagnetic interference with safety-related I&C functions. The facility is designed for passive, safe shutdown and to prevent uncontrolled release of radioactive material if normal electric power NEP is interrupted or lost. Uninterruptable power supplies automatically provide power to systems that support the safety functions protecting workers and the public.

The NEP system is designed to provide reasonable assurance that use or malfunction of electrical power systems could not damage the RPF or prevent safe RPF shutdown. The RPF also has a non-safety standby electrical power (SEP) system to reduce or eliminate process downtime due to electrical outages. A combination of uninterruptable power supplies and the SEP system will provide emergency electrical power to the RPF.

Other Auxiliary Systems

The RPF has the following auxiliary systems:

- Fire protection systems
- Communication systems

- Possession and use of byproduct, source, and SNM
- Cover gas control in the closed primary coolant system
- Other auxiliary systems, including utility systems, analytical laboratory, and chemical supply

Radiation Protection and Radioactive Waste Management

The NWMI RPF has a radiation protection program to protect the radiological health and safety of its workers. The program complies with the regulatory requirements of 10 CFR 19, "Notices, Instructions and Reports to Workers: Inspection and Investigations," 10 CFR 20, and 10 CFR 70. This program includes the elements of an ALARA program, radiation monitoring and surveying, exposure control, dosimetry, contamination control, and environmental monitoring. Additional details are provided in Chapter 11.0, "Radiation Protection and Waste Management," Section 11.1.2.

The radiation protection program provides a complete list of expected radiation and radioactive sources, including airborne, liquid, and solid sources. The radiation protection program also requires the development and implementation of procedures, identifies monitoring instrumentation and techniques, and specifies practices to be employed to verify compliance with the radiation dose limits and other applicable requirements. The basis and plans used to develop procedures for assessing and controlling radioactive wastes and the ALARA program are included.

Control of gaseous, liquid, and solid radioactive wastes in the RPF is described in Chapter 9.0, "Auxiliary Systems," Sections 9.6 and 9.7. NWMI's waste management program for radioactive wastes resulting from normal operations and maintenance of the RPF, including the required procedures, ensure that radiation exposures and releases of radioactive materials are adequately assessed and controlled. The waste management program addresses the following elements:

- Philosophy and approach to waste management
- Basis of procedures and technical specifications
- Organization, staffing, and associated training
- Document control and records management
- Review and audit committees for radioactive waste management activities
- Plans for shipping, disposal, and long-term waste storage

1.3.4 Experimental Facilities and Capabilities

The RPF does not include experimental facility SSCs that require research and development (R&D) to:

- Confirm adequacy of the facility design
- Identify and describe the R&D program that will completed to resolve any safety questions associated with such SSCs
- Schedule the R&D program to show that such safety questions will be resolved at or before the latest date stated in the application for completion of construction of the facility.

NWMI has and will continue to perform testing to validate the acceptable operating conditions for material and target solution compatibility at MURR and the DOE national laboratories prior to completion of RPF construction. Selected materials will be examined following irradiation testing at fluence levels expected in the operation of the target solution vessel for a 30-year lifetime. The testing will include specific work involving irradiation in a corrosive environment to examine the effects on the properties of selected raw materials and welded samples in an as-received and as-fabricated state. This work will be completed no later than December 31, 2017.

1.4 SHARED FACILITIES AND EQUIPMENT

The NWMI RPF does not share any systems or equipment with facilities not covered by this Construction Permit Application. The primary structure is the RPF. Three adjacent, separate buildings will be located on the site: an Administrative Building (outside of the protected area), a Waste Staging and Shipping Building for additional Class A waste storage (inside the protected area), and a Diesel Generator Building. These major facilities also receive, store/hold, or process chemicals, oil, diesel fuel, and other hazardous and radioactive materials.

1.5 COMPARISON WITH SIMILAR FACILITIES

As stated in Section 1.1, the NWMI RPF will produce ^{99}Mo through a fission-based process. NWMI has established a network of domestic university research reactors to irradiate LEU targets. Nearly all of the ^{99}Mo in the supply chain today is produced by irradiating ^{235}U with neutrons. Referred to as a fission reaction, six percent of collisions result in the formation of ^{99}Mo, as depicted in Figure 1-10. The process is well understood, reliable, predictable, and once extracted and purified, produces high-specific activity, ^{99}Mo. Radiopharmaceutical distributors in the U.S. use U.S. Food and Drug Administration-approved generators for ^{99}Mo produced by this method.

On a weekly basis, targets will be loaded around the reactor core and irradiated for approximately [Proprietary Information]. After irradiation, the targets will be mechanically removed from the core and placed in a cask or cooling tank. The targets will then be transported to the RPF using NRC-certified casks. Once the targets are received, the casks will be delidded and the targets poured into a nitric acid solution for dissolution.

Figure 1-10. Irradiating Uranium-235 with Neutrons to Form Molybdenum-99

Any gases produced from the dissolution step will be trapped and held until no longer an environmental concern and will then be vented through an offgas treatment system. The resulting solution will be separated into liquids containing unused uranium and ^{99}Mo. During the second stage, the ^{99}Mo liquid will be passed through several exchange columns to extract purified ^{99}Mo and rinse out the majority of other by-products.

The RPF is a conventional design, similar to the design used in other nuclear processing facilities.

1.5.1 Comparison of Physical Plant and Equipment

NWMI has developed extraction and purification chemistries, is designing and plans to construct an RPF to extract and purify ^{99}Mo, and intends to sell ^{99}Mo assuring a reliable, securable and domestic supply of this critical medical isotope. In addition, NWMI will recover and recycle the LEU.

The RPF will have unit processes for handling irradiated targets (i.e., hot cells, robust ventilation systems) and the ability to perform remote operations and maintenance. Parts of the process will be behind shielding walls, and decontaminated solutions will be processed or analyzed in gloveboxes, enclosures, or hoods. The process equipment is typical of that used in a DOE facility, with geometrically favorable tanks, IX columns, centrifugal contactors, evaporators, and batch solidification systems.

1.5.2 Comparison of Chemical Processes

The dissolution of target material uses a standard hot nitric acid process. The offgas treatment unit operations are well known and commercially available. The RPF Mo recovery and purification system will use [Proprietary Information] to selectively adsorb Mo from the irradiated target solution. The Mo purification process is very similar to the Cintichem process developed in the 1950s and 1960s by Union Carbide. Cintichem, Inc. used the process until 1990 as a means of purifying ^{99}Mo for use as a medical isotope. There are no NRC or DOE licensed facilities currently using this technology.

The uranium recovery process is a modification of a widely used uranium separation and purification process known as plutonium-uranium extraction (PUREX). The PUREX process was developed in the late 1940s and uses tributyl phosphate (TBP) to selectively remove uranium from a nitric acid solution typically containing a host of fission product and other actinide contaminants. The NWMI process uses similar chemistry but instead of a solvent process, the active agent is attached to a solid substrate.

The target fabrication processes and techniques are used in uranium processing and fuel fabrication facilities in the U.S., with standard nitric acid dissolution, small solvent extraction system, concentrator, and [Proprietary Information], and filling and sealing of the target hardware.

1.5.3 Comparison of Support Systems

Supporting systems, including ventilation, cooling water, waste processing, electrical power, and I&C, are conventional and generally require no unique features for the operation of the RPF.

1.6 SUMMARY OF OPERATIONS

The proposed action is the issuance of an NRC license under 10 CFR 50 and provisions of 10 CFR 70 and 10 CFR 30 that would authorize NWMI to construct and operate a ^{99}Mo RPF at a site located in Columbia, Missouri. RPF process activities will include:

- Receiving LEU from the DOE
- Producing LEU target materials and fabrication of targets
- Packaging and shipping LEU targets to the university reactor network for irradiation
- Returning irradiated LEU targets for dissolution, recovery, and purification of ^{99}Mo
- Recovering and recycling LEU to minimize radioactive, mixed, and hazardous waste generation
- Treating/packaging wastes generated by RPF process steps to enable transport to a disposal site.

The process design requirements are identified in NMWI-2013-049, *Process System Functional Specification*. [Proprietary Information]. The following summarizes key requirements for the RPF and the primary process systems:

- [Proprietary Information]
- [Proprietary Information]
- [Proprietary Information]
- Control/prevent flammable gas from reaching lower flammability limit conditions of 5 percent hydrogen gas (H_2); design for 25 percent of lower flammability limit
- Ensure that ^{235}U processing and storage meet security and criticality safety requirements

The RPF operating and process characteristics are provided in more detail in Chapter 4.0.

1.7 COMPLIANCE WITH THE NUCLEAR WASTE POLICY ACT OF 1982

The RPF does not produce high-level nuclear wastes or spent nuclear fuel. Therefore, the Nuclear Waste Policy Act of 1982 is not applicable to the RPF.

1.8 FACILITY MODIFICATIONS AND HISTORY

This Construction Permit and Operating License Applications are for the construction and operation of the NWMI RPF. There are no existing facilities at the proposed NWMI Discovery Ridge site, thus, no facilities modifications have occurred. This section is not applicable to the NWMI RPF.

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Chapter 2.0 – Site Characteristics

Construction Permit Application for Radioisotope Production Facility

NWMI-2013-021, Rev. 3
September 2017

Prepared by:
Northwest Medical Isotopes, LLC
815 NW 9th Ave, Suite 256
Corvallis, OR 97330

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Chapter 2.0 – Site Characteristics

Construction Permit Application for Radioisotope Production Facility

NWMI-2013-021, Rev. 3

Date Published:
September 5, 2017

Document Number: **NWMI-2013-021**		*Revision Number*: **3**
Title: **Chapter 2.0 – Site Characteristics** **Construction Permit Application for Radioisotope Production Facility**		
Approved by: **Carolyn Haass**	*Signature*: Carolyn C Haass	

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REVISION HISTORY

Rev	Date	Reason for Revision	Revised By
0	1/5/2014	Initial Application	Not required
1	5/19/2017	Incorporate changes based on responses to NRC Requests for Additional Information	C. Haass
2	8/5/2017	Modification based on ACRS comments	C. Haass
3	9/5/2017	Incorporate final comments from NRC Staff and ACRS; full document revision	C. Haass

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CONTENTS

FIGURES

TABLES

TERMS

Acronyms and Abbreviations

^{82}Rb	rubidium-82
ACI	American Concrete Institute
ALOHA	Areal Locations of Hazardous Atmospheres
BLEVE	boiling liquid expanding vapor explosion
CATSO	Columbia Area Transportation Study Organization
CFR	Code of Federal Regulations
CHM	Children's House Montessori Early Learning Center
CONUS	Continental United States
COU	Columbia Regional Airport
CUSEC	Central United States Earthquake Consortium State Geologists
DHSS	Department of Health & Senior Services
Discovery Ridge	Discovery Ridge Research Park
DOA	Department of Administration
EF scale	enhanced Fujita tornado intensity scale
ESRI	Environmental Systems Research Institute
F scale	(original) Fujita tornado intensity scale
FEMA	Federal Emergency Management Agency
FIPS	Federal Information Processing Standards
GIS	Geographical Information System
IBC	International Building Code
IDLH	immediately dangerous to life and health
IROFS	items relied on for safety
ISA	integrated safety analysis
ISCM	Islamic School of Columbia Missouri
LEL	lower explosion limit
MDE	Missouri Department of Education
MDNR	Missouri Department of Natural Resources
MMI	Modified Mercalli Intensity
MMRPC	Mid-Missouri Regional Planning Commission
MU	University of Missouri
NAD	National Geodetic Survey
NCES	National Center for Education Statistics
NMSZ	New Madrid Seismic Zone
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NWMI	Northwest Medical Isotopes, LLC
OGP	International Association of Oil and Gas Producers
RAWS	Remote Automatic Weather Station
RSAC	Radiological Safety Analysis Computer
REDI	Regional Economic Development, Inc.
RPF	radioisotope production facility
SARA	Superfund Amendments and Reauthorization Act
Terracon	Terracon Consultants, Inc.
TNT	trinitrotoluene
U.S.	United States
U.S.C.	United States Code

USCB	U.S. Census Bureau
USGS	U.S. Geological Survey

Units

°C	degrees Celsius
°F	degrees Fahrenheit
BTU	British thermal unit
cm	centimeter
ft	feet
ft^2	square feet
ft^3	cubic feet
g	g-force
gal	gallon
ha	hectare
hr	hour
in.	inch
$in.^2$	square inch
kg	kilogram
kgal	thousand gallons
kip	kilopound
km	kilometer
km^2	square kilometers
kPa	kilopascal
kW	kilowatt
L	liter
lb	pound
m	meter
m^2	square meter
m^3	cubic meter
MeV	million electron volt
Mgal	million gallons
mi	mile
mi^2	square mile
rem	roentgen equivalent in man
sec	second
yd	yard
yd^2	square yard

2.0 SITE CHARACTERISTICS

2.1 GEOGRAPHY AND DEMOGRAPHY

2.1.1 Site Location and Description

This subsection describes the location and important features of the Northwest Medical Isotopes, LLC (NWMI) proposed Radioisotope Production Facility (RPF) site.

2.1.1.1 Specification and Location

The proposed 3.0 hectares (ha) (7.4-acre) site is situated in Boone County, Missouri, within the University of Missouri (MU) Discovery Ridge Research Park (Discovery Ridge) in Columbia, Missouri, north of Discovery Ridge Drive. The site is situated in central Missouri approximately 201 kilometers (km) (125 miles [mi]) east of Kansas City and 201 km (125 mi) west of St. Louis. The site is 7.2 km (4.5 mi) south of United States (U.S.) Interstate Highway 70 just to the north of U.S. Highway 63. The Missouri River lies 15.3 km (9.5 mi) to the west of the site. The site is located 5.6 km (3.5 mi) to the southeast of the main MU campus and is shown on the map on Figure 2-1. Figure 2-2 provides the 8 km (5-mi) radius from the center of the facility and shows highways, rivers, and other local bodies of water.

The approximate center of the proposed RPF (NAD 83, 1983) is:

Latitude and Longitude

Longitude:	92° 16' 34.63"
Latitude:	38° 54' 3.31"

Universal Transverse Mercator Coordinates (meters [m])

Northing:	4306031 m
Easting:	562755 m
Zone:	15S

Missouri State Plane Coordinates (U.S. Survey feet [ft])

North:	1116979.02 ft US
East:	1704082.07 ft US
FIPS Zone:	Missouri Central 2402

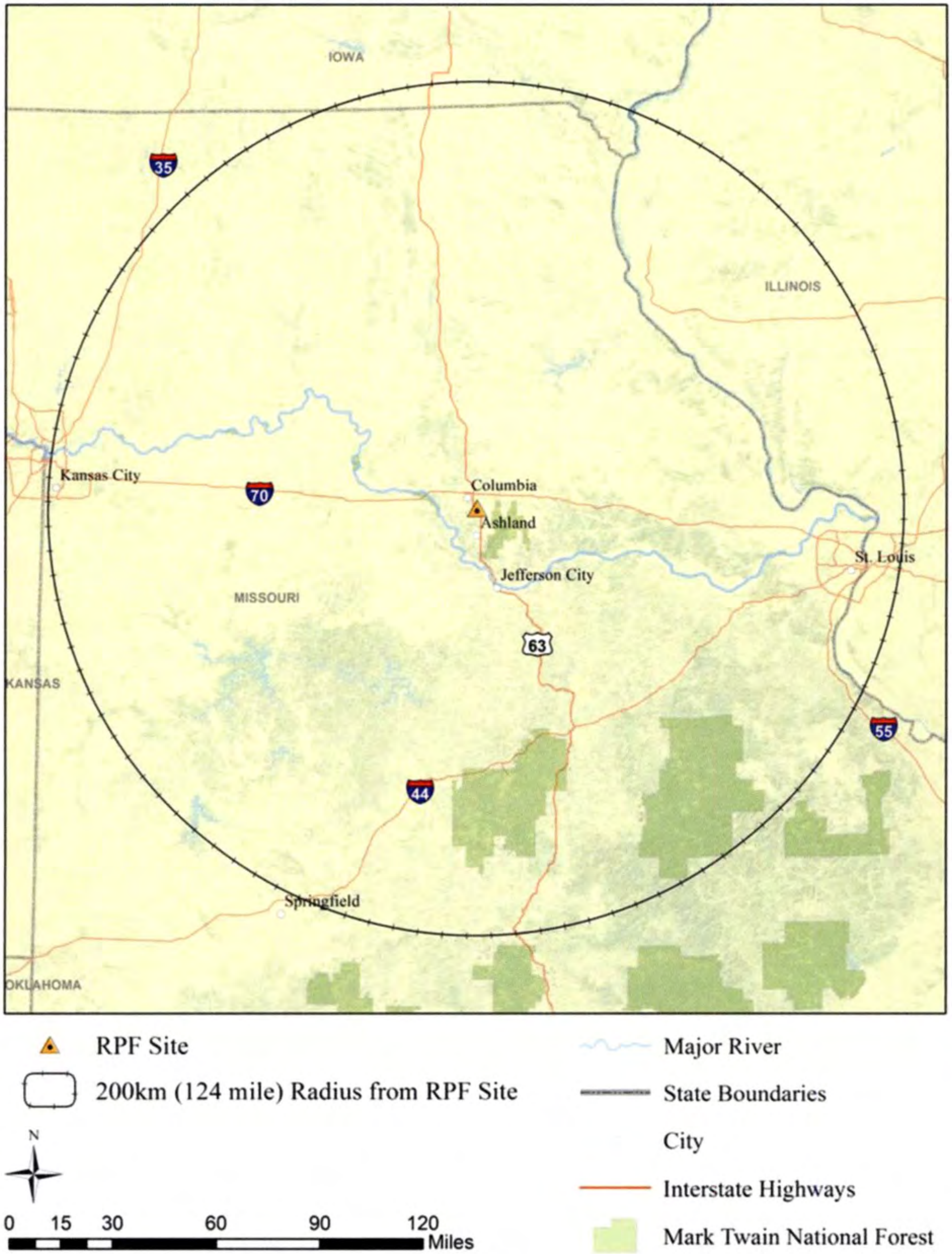

Figure 2-1. 200 km (124 mi) Radius with Cities and Roads

Figure 2-2. Illustration of 8 km (5-mi) Radius from the Center of the Facility

2.1.1.2 Boundary and Zone Area Maps

Figure 2-3 shows the boundaries and zones applicable to the proposed RPF site. The square area near the center of the site within which all safety-related structures are located gives the rough location and size of the operations boundary in accordance with ANSI/ANS-15.7, *Research Reactor Site Evaluation*, and ANSI/ANS-15.16, *Emergency Planning for Research Reactors*. The Emergency Planning Zone is encompassed by the site boundary using the guidance in:

- ANSI/ANS-15.16, *Emergency Planning for Research Reactors*
- Regulatory Guide 2.6, *Emergency Planning for Research and Test Reactors*
- Title 10, *Code of Federal Regulation*, Part 50.54 (10 CFR 50.54), "Conditions of Licenses"
- 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities."

The site boundary is the property line around the perimeter of the RPF site in accordance with ANSI/ANS-15.7 and ANSI/ANS-15.16. The controlled area (also referred to as the exclusion area) is the area within the site boundary in accordance with 10 CFR 20, "Standards for Protection Against Radiation," Subpart 20.1003, "Definitions," and 10 CFR 70.61(f), "Performance Requirements." The area directly under the facility operating license will also be delineated by the site boundary.

Figure 2-4 shows the highways, railways, and waterways within the 8 km (5-mi) radius of the RPF site. The approximately 3.0 ha (7.4-acre) RPF site is located entirely on property owned by MU. The site presently consists of grass fields. Access to the site is provided from Discovery Drive and Discovery Parkway. The RPF site is primarily relatively flat surfaces at an elevation of 231 m (758 ft). Figure 2-5 shows the topography within the vicinity of the RPF site.

Estimates of population density around the proposed project site included data from the most recent census year (USCB, 2010). Block groups and associated populations were identified within the 8 km (5-mi) radius of the RPF site using ArcGIS 10.1 (ESRI, 2011). The associated population was divided by the calculated area (square mile [mi^2]) of each block group. The resulting population density was used to determine if the block group could be classified as either rural or urban. Block groups with a population density of more than 500 people/mi^2 were identified as urban. Block groups with a population density of lesser than 500 people/mi^2 were identified as rural. Urban or rural zones are identified in Figure 2-6.

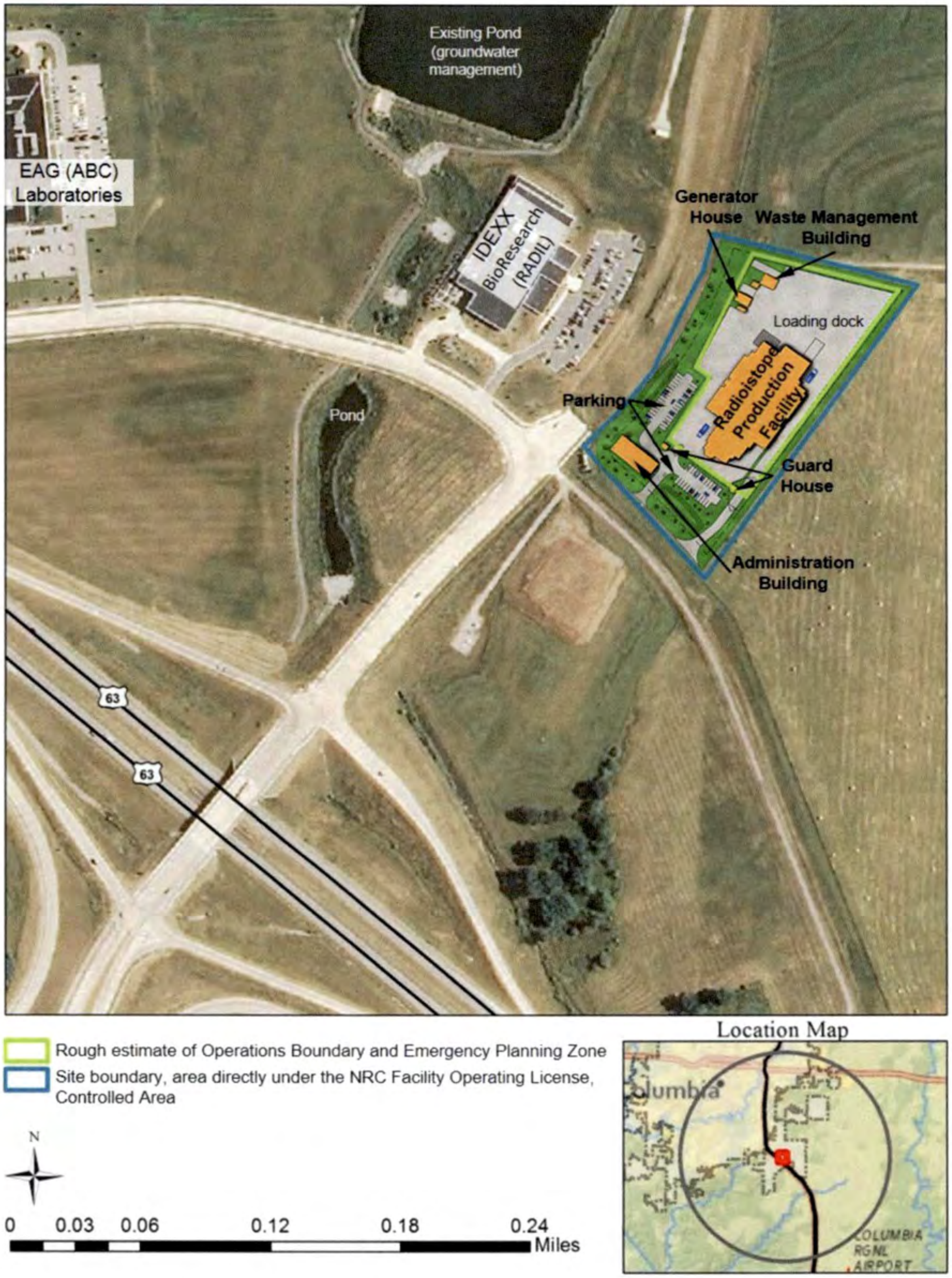

Figure 2-3. Boundaries and Zones Associated with the Facility

Figure 2-4. Prominent Features in Site Area

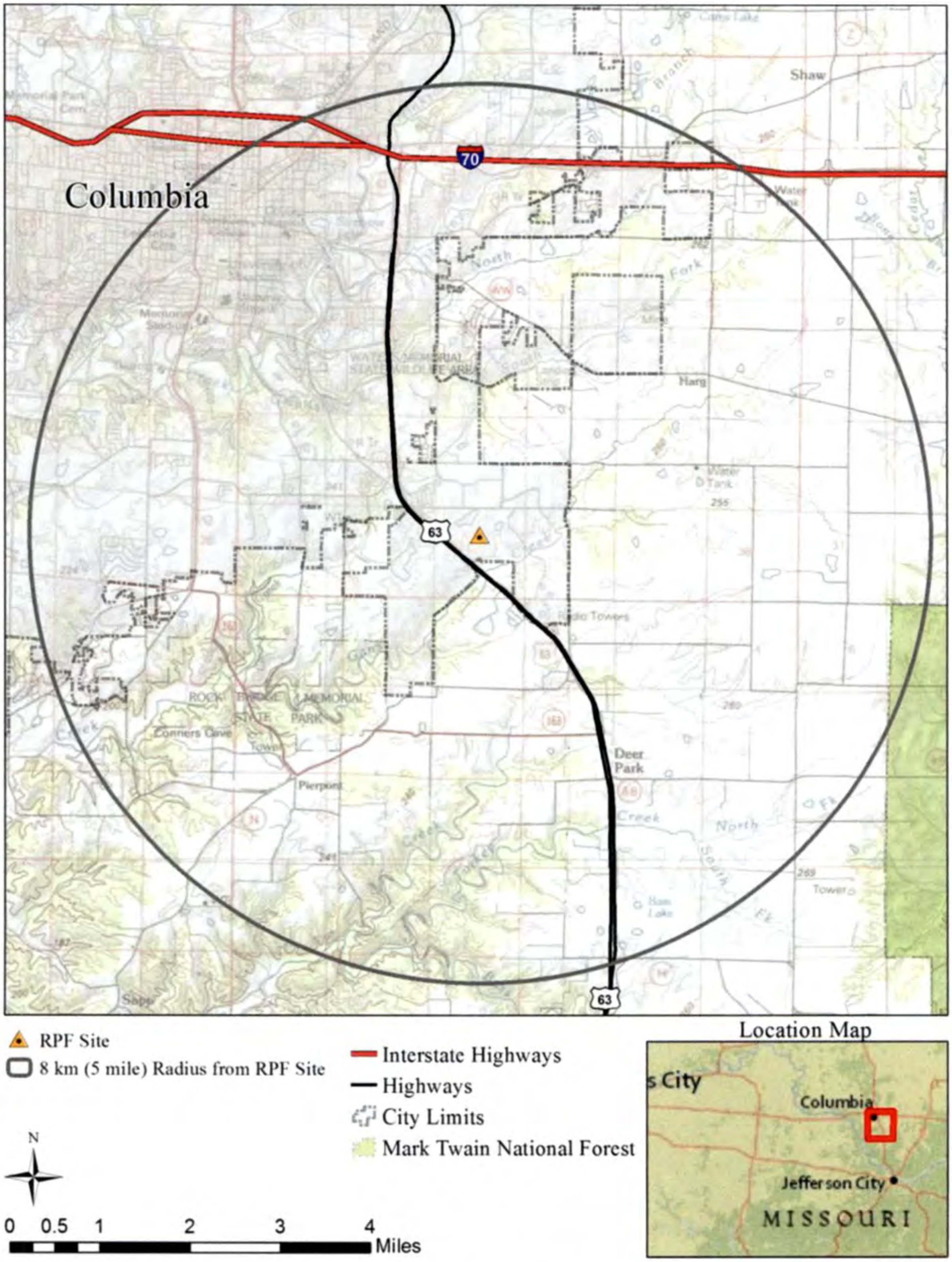

Figure 2-5. Topography in Site Area

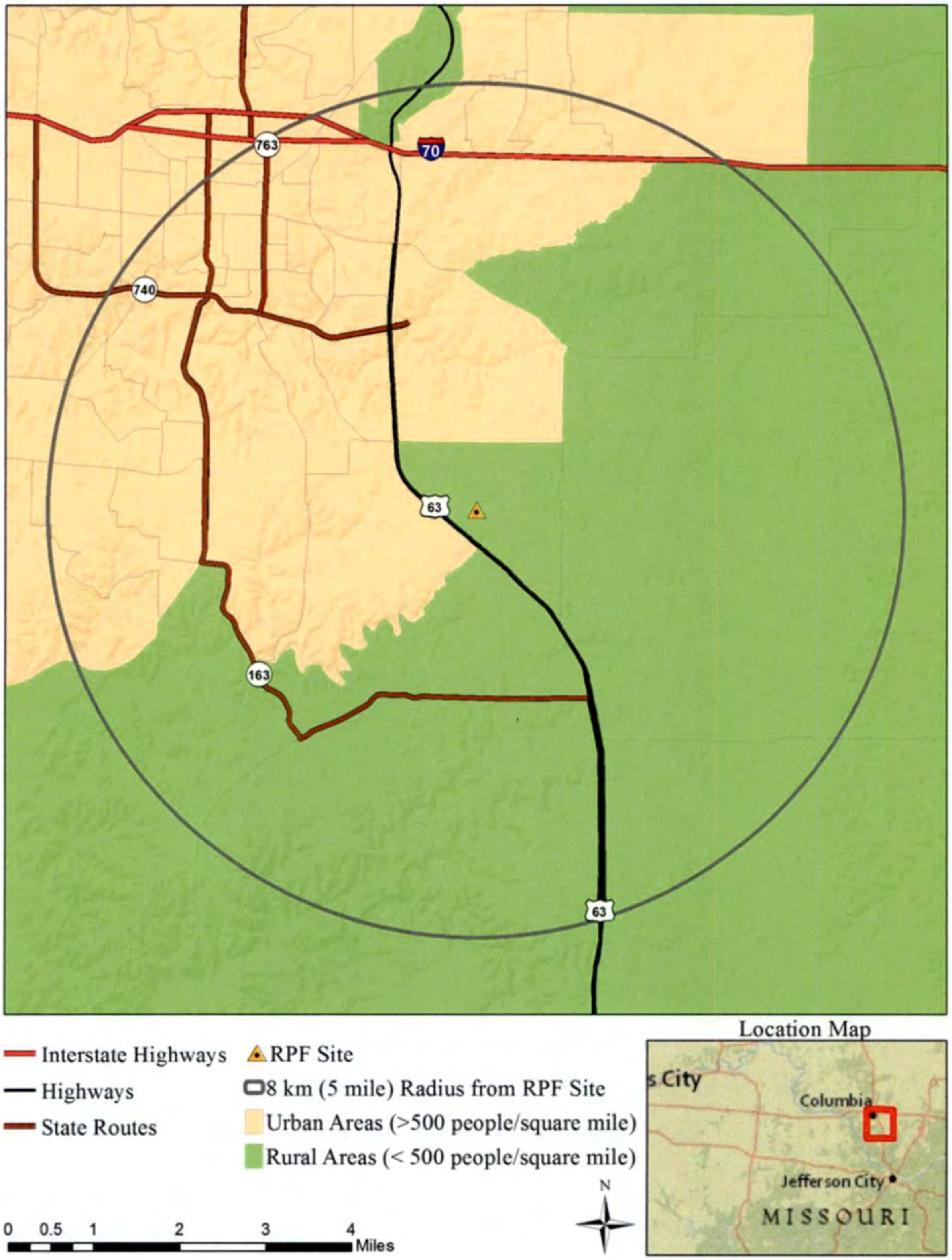

Figure 2-6. The Rural and Urban Zones Surrounding the Radioisotope Production Facility

2.1.2 Population Distribution

This subsection describes the population distribution within 8 km (5.0 mi) of the center point of the safety-related area at the proposed site. The information includes estimates of the resident and transient populations for the most recent census year (2010) and projections of the resident and transient populations for the following future years:

- Year submitting Construction Permit Application (2015)
- Year of submitting Operating License Application (2018)
- Five years after submitting Construction Permit Application (2020)
- Five years after submitting Operating License Application (2023)
- Approximate expected end of Operating License period (2050)
- Five years after approximate expected end of Operating License period (2055)

Estimates and projections of resident and transient populations around the proposed project site are divided into five distance bands—concentric circles at 0-1 km (0-0.6 mi), 1-2 km (0.6-1.2 mi), 2-4 km (1.2-2.5 mi), 4-6 km (2.5-3.7 mi), and 6-8 km (3.7-5.0 mi) from the center point of the RPF—and 16 directional sectors (with each direction sector centered on one of the 16 compass points). For each segment formed by the distance bands and directional sectors, the resident population was estimated using U.S. Census Bureau 2010 census data, and the transient population was estimated using the best available data for major employers, schools, medical facilities, and lodging facilities. Collected transient population data is intended to represent 2010 population levels.

The future resident and transient population growth in each distance/direction segment was projected using specific growth rates that depend on whether the segment is located in the city of Columbia or in Boone County. The specific growth rates used in these areas are explained in the following paragraphs.

The City of Columbia comprehensive land use plan (City of Columbia, 2013), presents projections on the city's future population calculated using several possible population growth rates. The plan states that the Columbia Area Transportation Study Organization (CATSO) model projects a greater rate of population growth and is considered the most reasonable and conservative basis for estimating the city's future population. According to the plan, the CATSO model growth rate was calculated by using historic population data and land use trends, which are then projected forward to estimate future growth. Based on these projections, the CATSO model estimated that the rate of population growth (growth rate) is 1.5 percent annually. This growth rate was used to project future populations for areas within the analysis area that are within the Columbia city limits. The 2010 estimated resident and transient population in each distance/direction segment that is located partially or entirely within the city boundaries was increased by 1.5 percent each year from 2011 to 2050.

The Missouri Department of Administration (DOA) provides state and county population projections that were developed using the cohort-component method (DOA, 2008). The cohort-component method reviews recent historical patterns to determine age- and sex-specific rates of fertility, mortality, and migration. The DOA used the 2000 Census as a base for population counts. The base count is then advanced at five-year intervals to the year 2030 by using projected survival rates and net migration rates by age and sex. The DOA projections show that the population of Boone County is expected to increase by 7.9 percent for the five-year period from 2010 to 2015, by 7.2 percent from 2015 to 2020, by 6.2 percent from 2020 to 2025, and by 5.0 percent for the period from 2025 to 2030. For each five-year period, the percent growth was divided by five to give the estimated annual growth rate within that period. The annual growth rates were used to project future populations for the areas around the project site that are entirely outside the boundaries of the city of Columbia. The estimated 2010 resident and transient population in each distance/direction segment that is located entirely outside of the city boundaries was increased by 1.58 percent each year from 2011 to 2015, by 1.44 percent from 2016 to 2020, by 1.24 percent from 2021 to 2025, and by 1.0 percent from 2026 to 2030. The growth rate of 1.0 percent was used for the period from 2031 to 2050.

The following subsections described the resident and transient population distribution surrounding the proposed RPF site.

2.1.2.1 Resident Population

The permanent residences nearest to the proposed RPF site were identified through an examination of aerial photographs and geographic information system (GIS) data files using ArcGIS 10.1 (ESRI, 2011). There are two permanent residences located approximately 0.48 km (0.3 mi) from the center point, one to the south and the other to the northeast. These two houses are the closest residences to the center point of the safety-related area.

Figure 2-7 shows places of significant population groupings (incorporated cities and unincorporated villages) within 8 km (5.0 mi) of the center point of the safety-related area. The map includes concentric circles drawn at distances of 1 km (0.6 mi), 2 km (1.2 mi), 4 km (2.5 mi), 6 km (3.7 mi), and 8 km (5 mi) from the center point, and is divided into 16 directional sectors, with each directional sector consisting of 22.5 degrees centered on one of the 16 compass points. Table 2-1 shows the closest permanent resident within each of the 16 sectors.

The 2010 resident population within the 1 km (0.6 mi) and 2 km (1.2 mi) concentric circles was estimated based on the number of occupied houses (as identified through an examination of aerial photographs) and the average number of people per household (as reported by the U.S. Census Bureau). U.S. Census Bureau data indicates that Boone County has an average of 2.36 people per household (USCB, 2013).

Table 2-1. Closest Permanent Residents Within Each Compass Section Around the Proposed Site

Quadrant	Nearest resident	
	km	mi
North to North-Northeast	1.4	0.86
North-Northeast to Northeast	0.6	0.36
Northeast to East-Northeast	2.0	1.22
East-Northeast to East	1.1	0.7
East to East-Southeast	1.8	1.1
East-Southeast to Southeast	2.0	1.24
Southeast to South-Southeast	0.9	0.55
South-Southeast to South	0.8	0.48
South to South-Southwest	0.4	0.27
South-Southwest to Southwest	1.4	0.89
Southwest to West-Southwest	1.4	0.87
West-Southwest to West	2.0	1.23
West to West-Northwest	0.9	0.58
West-Northwest to Northwest	1.0	0.65
Northwest to North-Northwest	1.7	1.04
North-Northwest to North	1.4	0.86

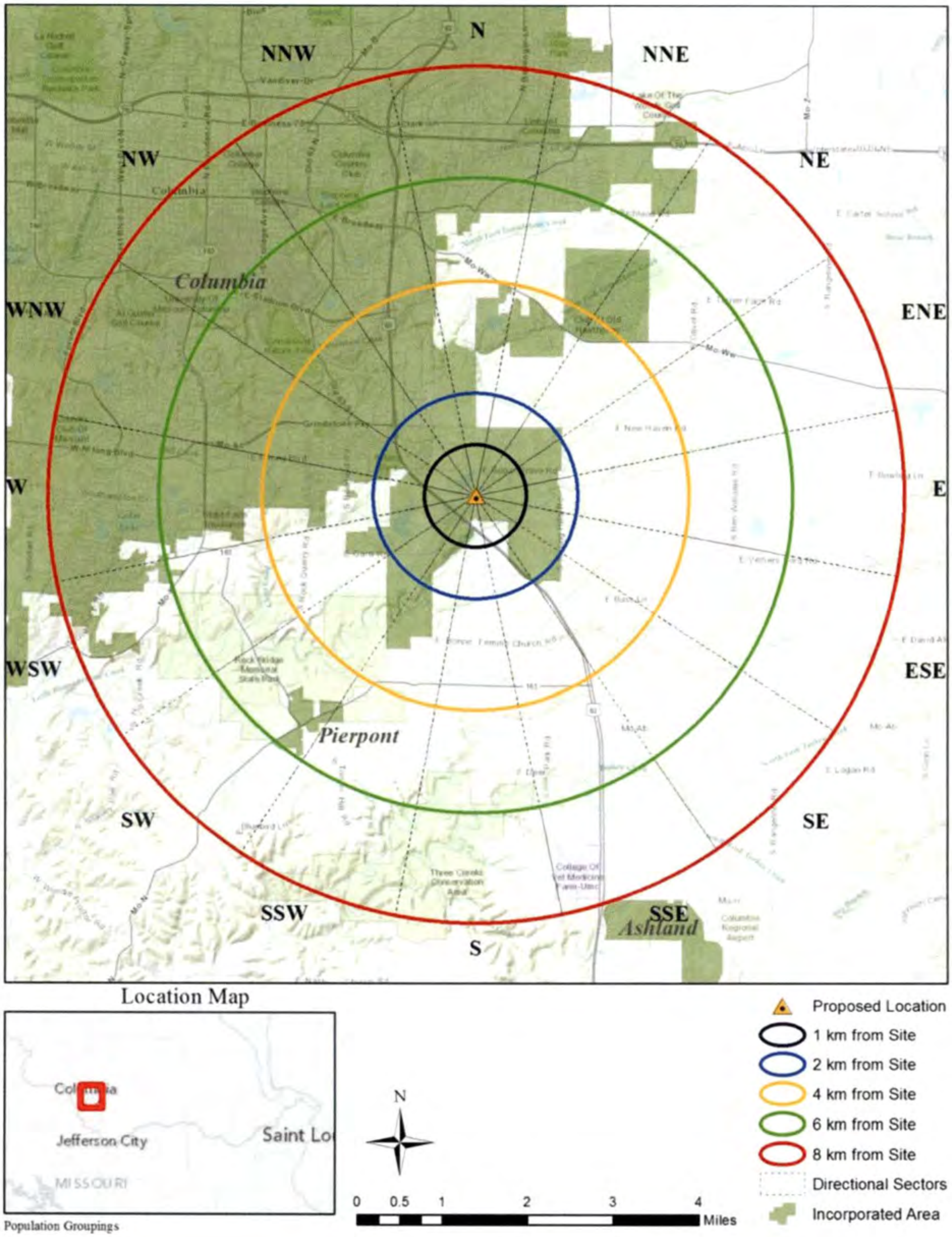

Figure 2-7. Population Groupings

The 2010 resident population estimate was derived by multiplying the number of occupied houses by 2.36 people per house and rounding to the nearest whole number. The total resident population estimated in this manner for 2010 is 205 people at a distance of 0-1 km (0-0.6 mi) from the proposed site, and 1,862 people at a distance of 1-2 km (0.6-1.2 mi). These population estimates are shown in Table 2-2, along with estimates for other distances. Figure 2-8 shows the population estimates divided into the distance/direction sections.

Table 2-2. Resident Population Distribution within 8 km (5 mi) of the Proposed Site

Year	Distance band (km)					
	0 – 1	1 – 2	2 – 4	4 – 6	6 – 8	Total 0 – 8
2010	205	1,862	7,070	16,919	21,508	**47,564**
2014	218	1,974	7,495	17,936	22,801	**50,423**
2015	221	2,004	7,608	18,205	23,143	**51,181**
2019	234	2,124	8,063	19,296	24,530	**54,247**
2020	238	2,156	8,184	19,585	24,897	**55,060**
2045	291	2,628	9,991	23,948	30,428	**67,287**
2050	313	2,820	10,727	25,728	32,683	**72,271**

The U.S. Census Bureau 2010 census block and tract data (USCB, 2012) was used to estimate the resident population within the 4 km (2.5 mi), 6 km (3.7 mi), and 8 km (5.0 mi) distance bands. For each segment formed by the distance bands and directional sectors, the percentage of each census tract's land area that falls, either partially or entirely, within that segment was calculated using ArcMap 10 GIS software (ESRI, 2011). The equivalent proportion of each census tract's population was then assigned to that segment. If portions of two or more census tracts fall within the same segment, the proportional population estimates for the census tracts were summed to obtain the population estimate for that segment. Table 2-2 shows total 2010 population estimates within the 4 km (2.5 mi), 6 km (3.7 mi), and 8 km (5.0 mi) distance bands, and Figure 2-8 shows the population estimates divided into the distance/direction sections.

Using the methodologies described above, the 2010 resident population estimates within the distance bands and directional sectors were extrapolated to the years 2014, 2015, 2019, 2020, 2045, and 2050. Table 2-2 shows that total projected resident population for these years within the distance bands, and Figure 2-9 to Figure 2-14 show the projections for these years divided into the distance/direction sections.

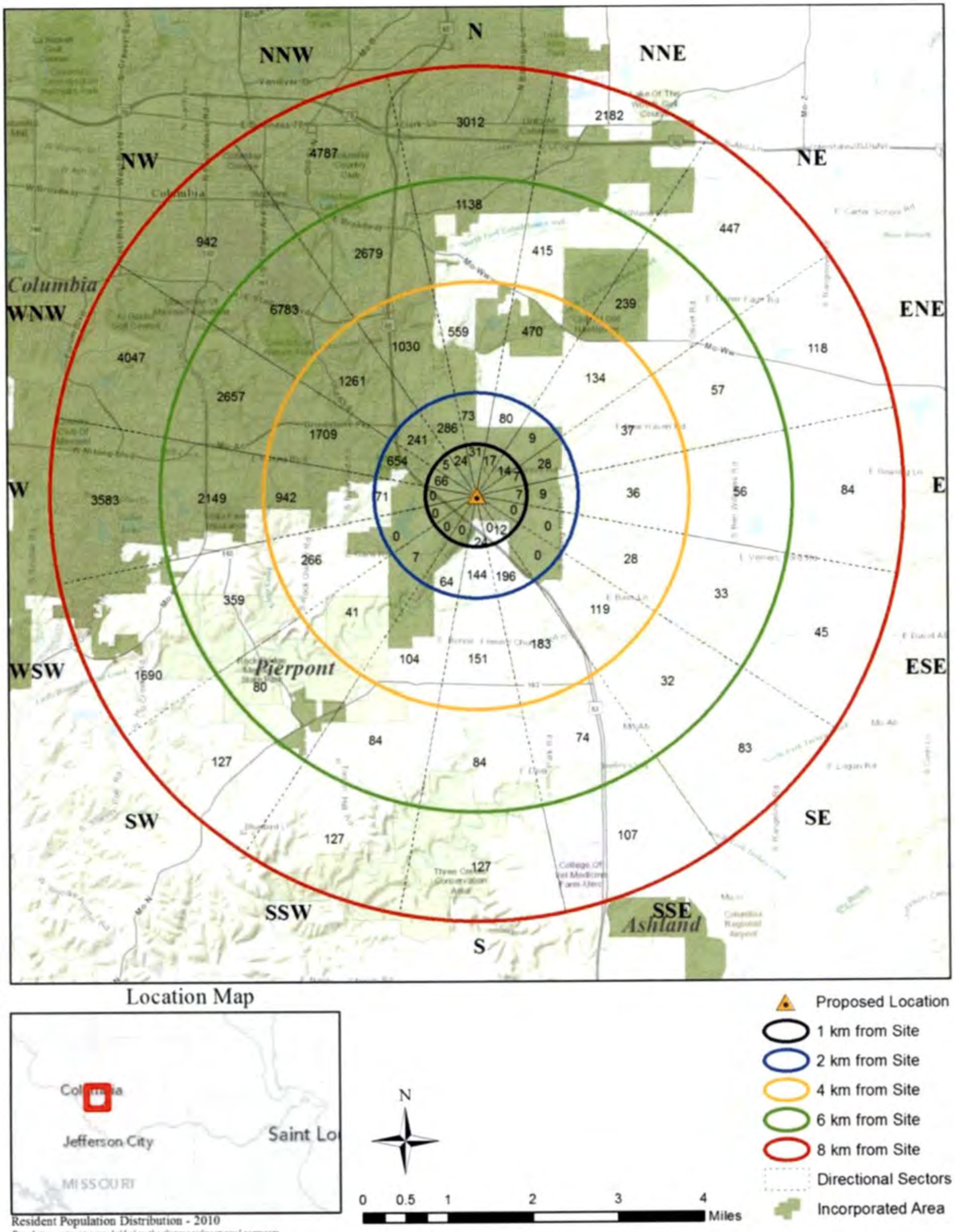

Figure 2-8. Resident Population Distribution – 2010

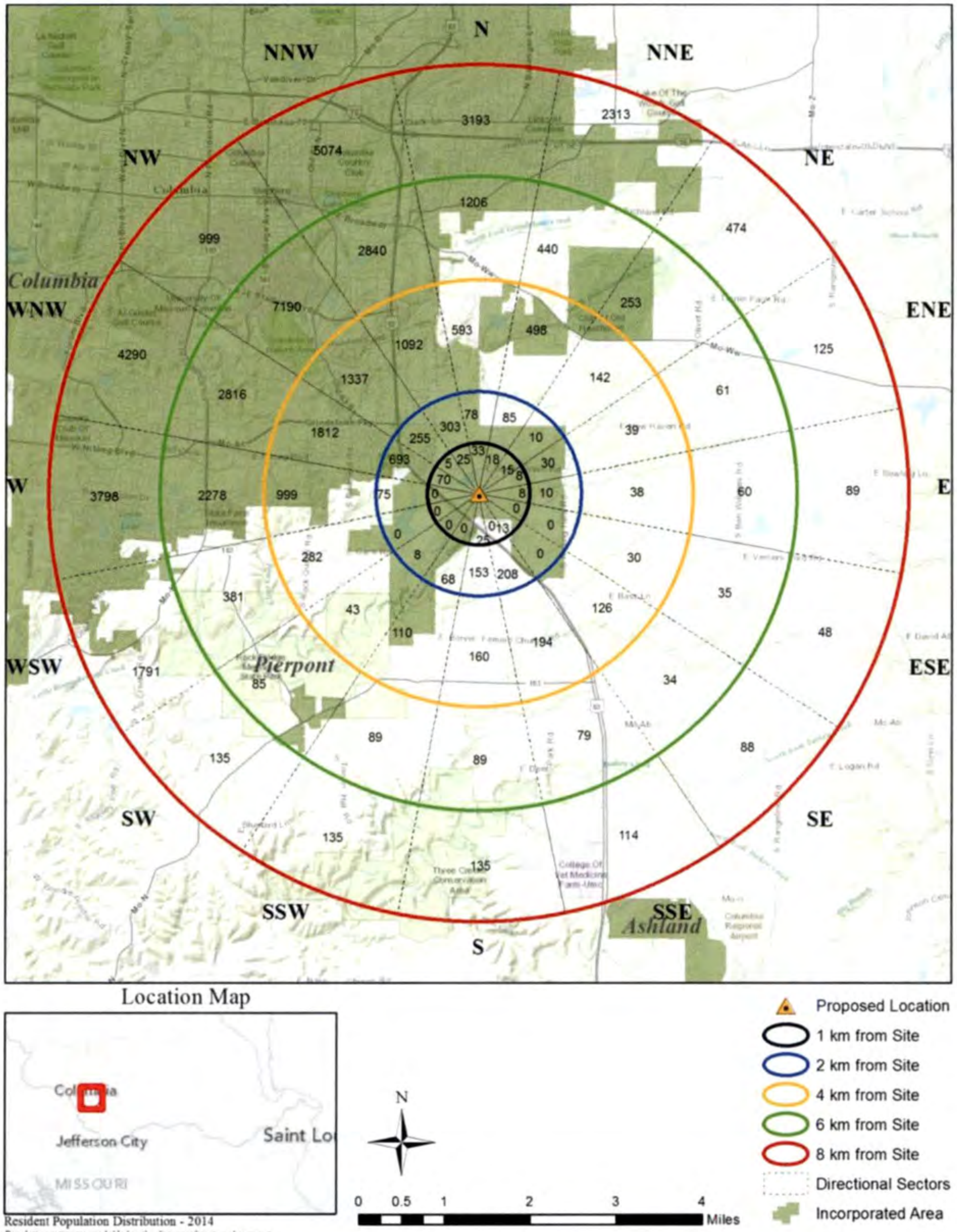

Figure 2-9. Resident Population Distribution – 2014

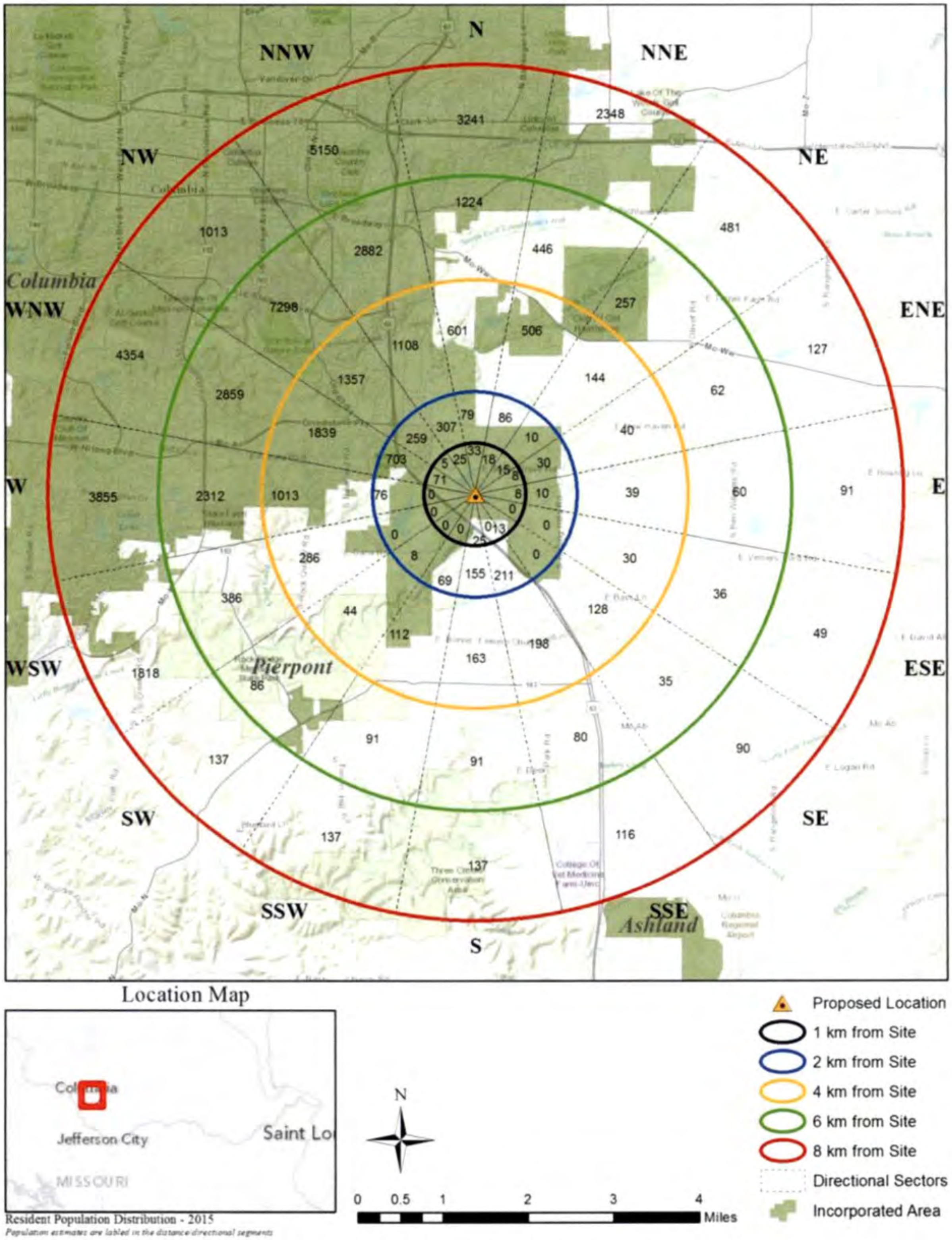

Figure 2-10. Resident Population Distribution – 2015

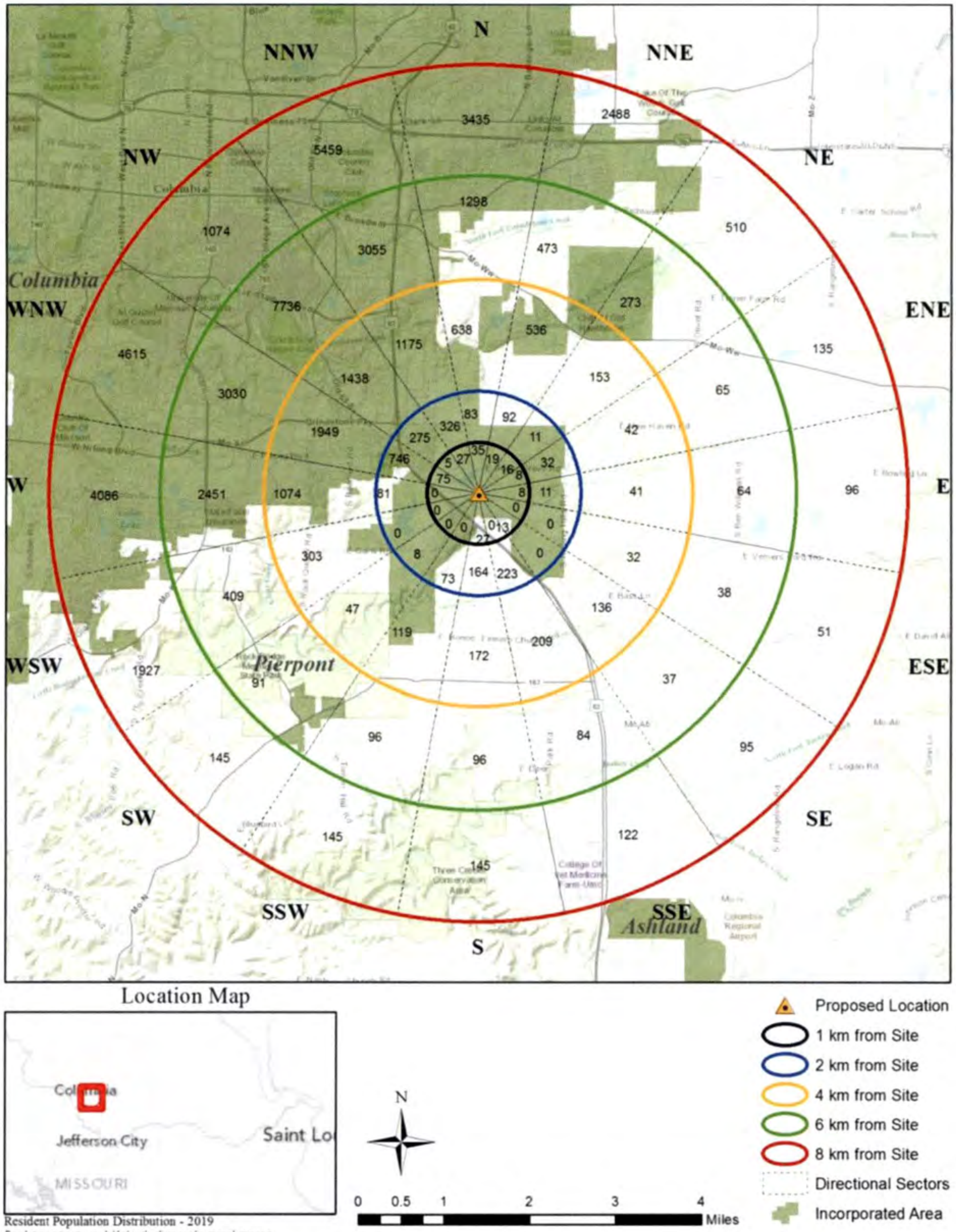

Figure 2-11. Resident Population Distribution – 2019

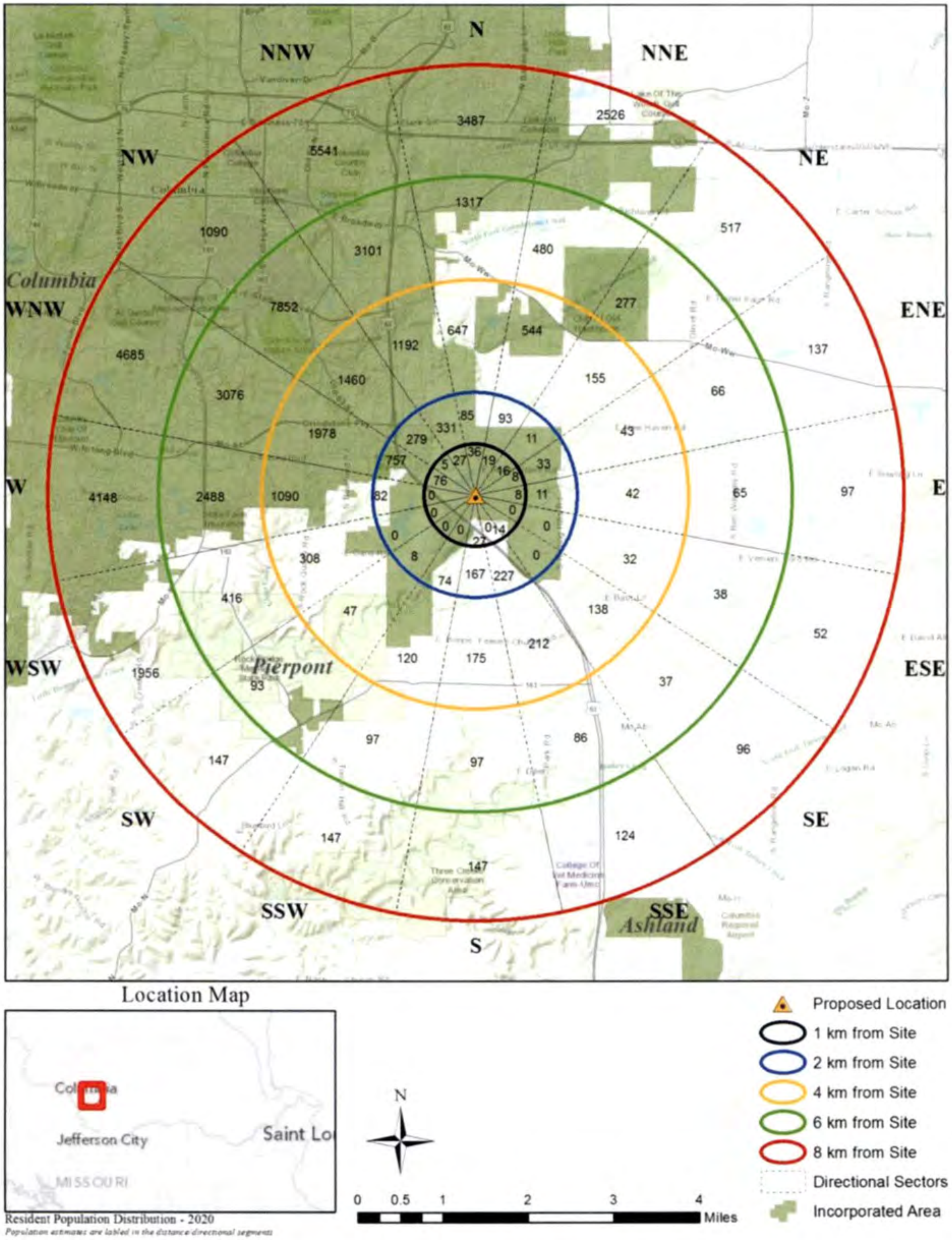

Figure 2-12. Resident Population Distribution – 2020

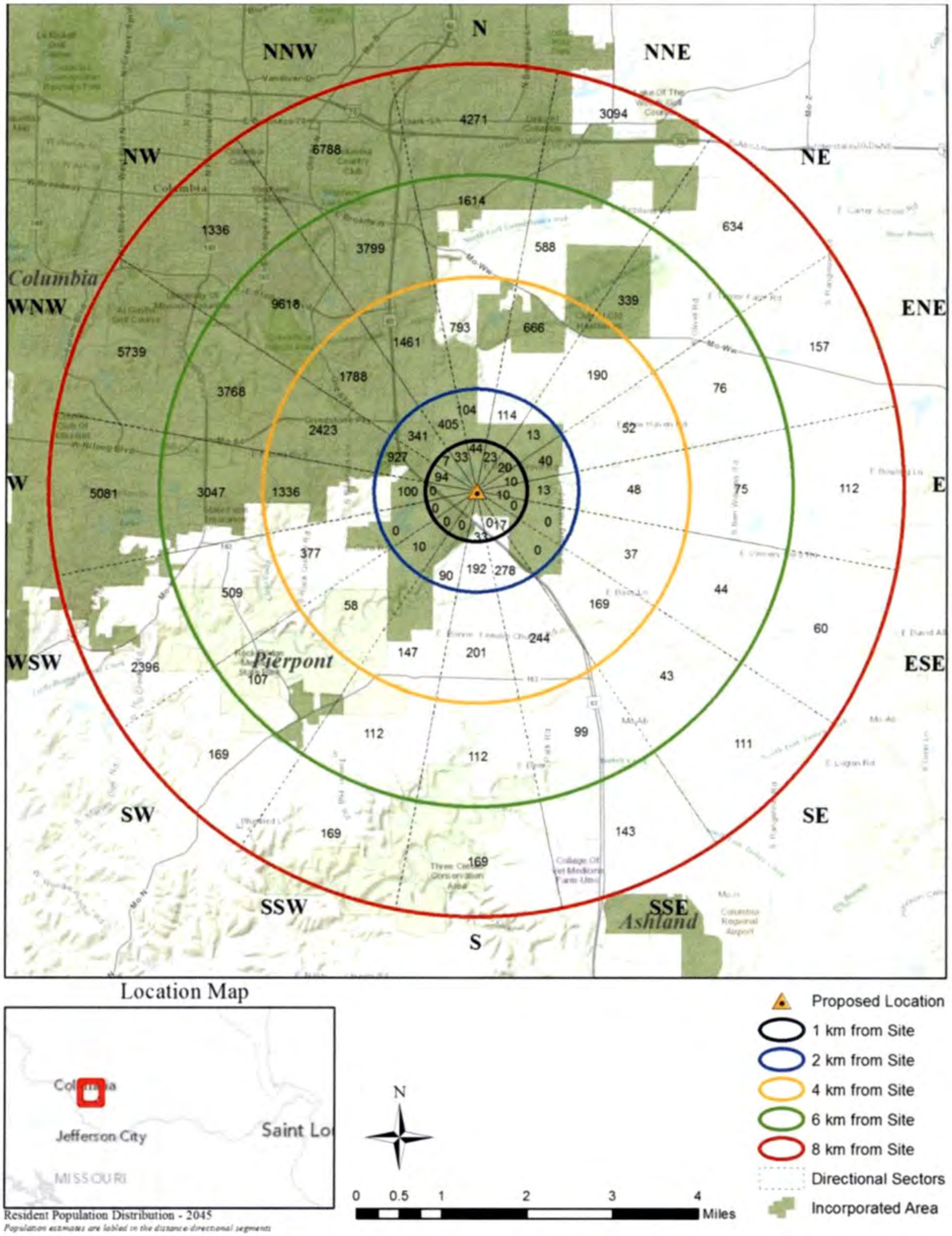

Figure 2-13. Resident Population Distribution – 2045

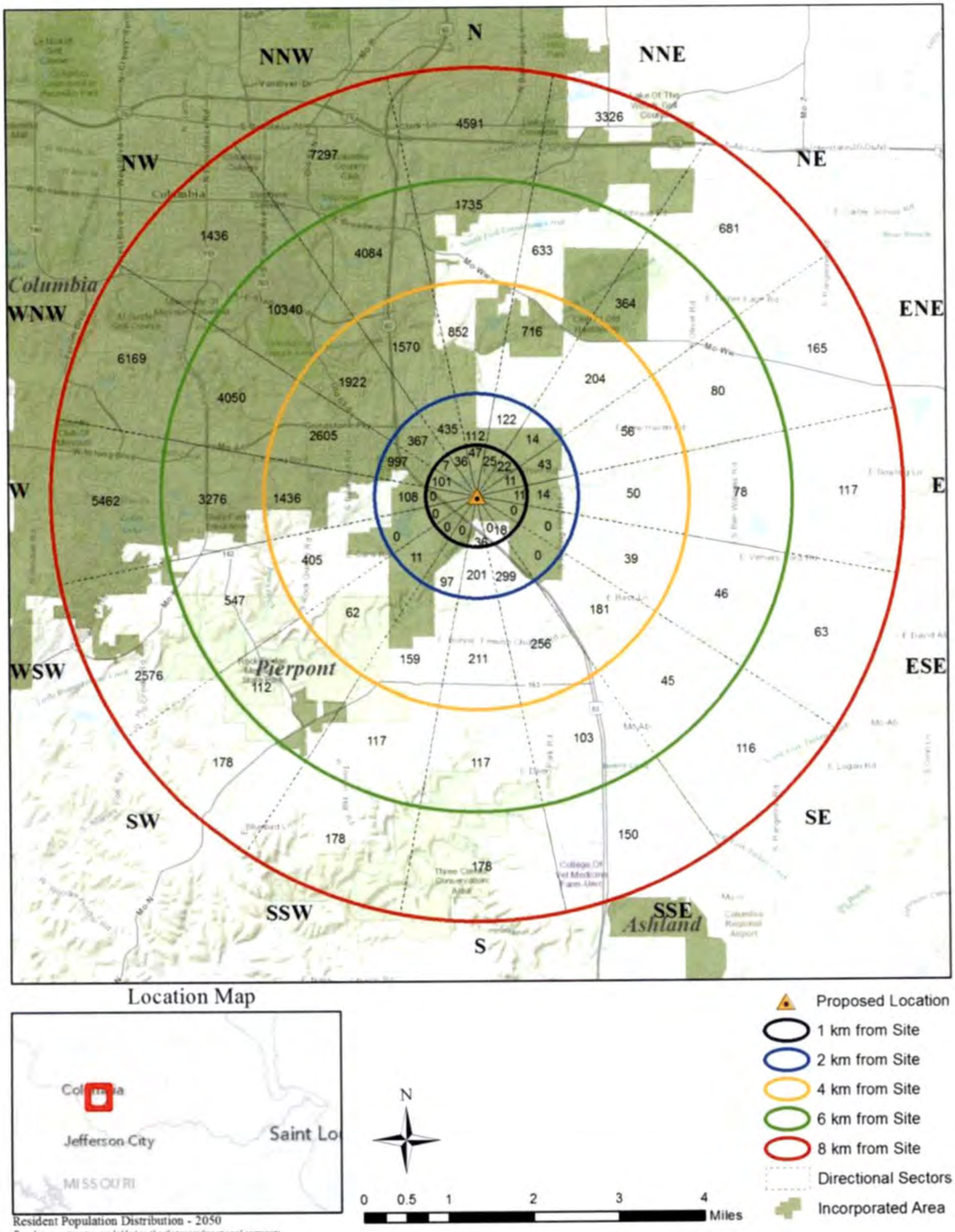

Figure 2-14. Resident Population Distribution – 2050

2.1.2.2 Transient Population

In the addition to permanent residents around the proposed RPF site, there are people who enter this area temporarily for activities such as employment, education, medical care, and lodging. Although, some residents may not leave the safety-related area for any of these above activities, it is assumed that the estimated transient population estimates represent the population that is using the area temporarily. These transient populations were estimated based on data obtained from local officials, tourist boards, and government agency websites for major employers, schools, medical facilities (hospitals and nursing homes), and lodging facilities (hotels and motels) within 8 km (5.0 mi) of the center point. Transient populations using recreation sites were not used as part of the estimate because data could not be obtained for facility daily use.

Table 2-3 lists the major employers identified within 8 km (5.0 mi) of the proposed site, the directional sector and distance band within which each employer is located, and the best available estimate of the total number of people employed at that location. Data from Regional Economic Development, Inc. was used to estimate the number of employee per major employers within the safety-related area (REDI, 2011).

Table 2-3. Employers (2 pages)

Facility	Directional sector	Distance band (km)	Employment
ABC Laboratories, Inc.	W	0 to 1	348
Discovery Office Park (2016)	W	0 to 1	250[a]
Columbia School District - New Haven[b]	NW	1 to 2	23
Boone County Public Works	SSE	1 to 2	74
Central Regional Conservation Office (2013)	SW	1 to 2	40[a]
KOMO	SE	1 to 2	6[f]
Magellan Pipeline	SSE	1 to 2	15[a]
Columbia Auto Mart	SE	1 to 2	8[a]
Columbia School District – Cedar Ridge[b]	N	2 to 4	15
Jones Honda	SSE	2 to 4	8[a]
MBS Textbook Exchange	NW	2 to 4	1,084
State Farm Insurance Companies	WNW	2 to 4	1,043
U.S. Postal Service 341[c]	NW	2 to 4	43
Woodhaven	WNW	2 to 4	220
Meeks Lumber	SSE	2 to 4	10[a]
MFA, Inc.	NW	2 to 4	250
Equine Medical Services	SSE	4 to 6	6[a]
University of Missouri[d]	NW	4 to 6	3,162
University of Missouri[d]	WNW	4 to 6	611
University of Missouri[d]	NNW	4 to 6	2
Columbia School District – Gentry Middle School[b]	W	4 to 6	64
Columbia School District – Rock Bridge[b]	WSW	4 to 6	40
Columbia School District – Rock Bridge High School[b]	W	4 to 6	107
Columbia School District – Sheppard Boulevard[b]	NNW	4 to 6	30
Boyce and Bynum Pathology Laboratories, P.C.	N	4 to 6	369
U.S. Postal Service[c]	W	4 to 6	43
Boone County National Bank[e]	WNW	4 to 6	16
Boone County National Bank[e]	NNW	4 to 6	16

Table 2-3. Employers (2 pages)

Facility	Directional sector	Distance band (km)	Employment
Missouri Employers Mutual Insurance	NNW	4 to 6	201
University of Missouri[d]	NW	6 to 8	3,273
University of Missouri[d]	WNW	6 to 8	1,581
University Hospital and Clinics – Women's and Children's Hospital[f]	N	6 to 8	1,412
University Hospital and Clinics[f]	NW	6 to 8	2,867
Columbia School District – Benton[b]	NNW	6 to 8	23
Columbia School District – Douglass High School[b]	NW	6 to 8	15
Columbia School District – Grant[b]	NW	6 to 8	23
Columbia School District – Jefferson Junior High[b]	NW	6 to 8	65
Columbia School District – Lee[b]	NW	6 to 8	21
Boone Hospital Center	NW	6 to 8	1,647
City of Columbia	NW	6 to 8	1,286
U.S. Department of Veterans Affairs	NW	6 to 8	1,250
Columbia College	NW	6 to 8	490
Boone County Government	NW	6 to 8	291
U.S. Postal Service[c]	NW	6 to 8	43
CenturyLink	NW	6 to 8	230
U.S. Department of Agriculture	NW	6 to 8	258
Boone County National Bank[e]	W	6 to 8	16
Boone County National Bank[e]	NW	6 to 8	16
Boone County National Bank[e]	NW	6 to 8	16
Boone County National Bank[e]	NNW	6 to 8	16
Boone County National Bank[e]	NNE	6 to 8	16
Total:			**22,615**

Sources:

DHSS, 2013, "DHSS Community Data Profiles – Hospital Revenues from 2010-2012," http://health.mo.gov/data/CommunityDataProfiles/index.html, Missouri Department of Health & Senior Services, Jefferson City, Missouri, accessed September 5, 2013.

MDE, 2013, "District Student Staff Ratios – Columbia 93," Missouri Department of Education, Jefferson City, Missouri.

REDI, 2011, "2011 Fact Book Columbia/Boone County Missouri," http://www.columbiaredi.com/wp-content/uploads/2011/04/REDI-Fact-Book-11.pdf, Regional Economic Development, Inc., Columbia, Missouri.

[a] Estimated.

[b] Employee estimates are based on school-to-student and administrator-to-student ratios. These are the estimated personnel who are most likely to be onsite 9 hours (hr)/day, 5 days/week.

[c] The total number of post office employees (341) were divided by the total number of branches (8) located within the Columbia metropolitan area and distributed accordingly.

[d] The total number of University of Missouri employees (8,630) is proportional to the area of the University of Missouri that lies within the distance/direction sector based on the area.

[e] The total number of Boone County National Bank employees (275) were divided by the total number of branches (17) and distributed accordingly.

[f] The total number of University Hospital and Clinics employees (4,279) is proportional to the number of licensed beds at the University Hospital and Clinics and the Women's and Children's Hospital.

MU is located in several of the distance/direction sections. For the employee estimate, the percentage of the university's area that falls, either partially or entirely, within that segment was calculated using ArcMap 10 GIS software (ESRI, 2011). The equivalent proportion of university's employment was then assigned to that segment. To estimate the percentage of employees for the Columbia School District within the safety-related area, the distance/direction section for each school was noted, and the number of employees at each school was estimated using teacher-to-student and administrator-to-student ratios provided by the Missouri Department of Education (MDE, 2013). The University Hospital and Clinics operates several facilities within the safety-related area. The majority of facilities are located near MU in one distance/direction section; however, the Women's and Children's Hospital is separate from these facilities. The number of licensed rooms that are managed by the University Hospital and Clinics was used to estimate the proportion of employees at the Women's and Children's Hospital (DHSS, 2013). For the population estimate for the U.S. Postal Service and Boone County National Bank, the total number of employees was divided by the total number of branches in Boone County and then assigned to the appropriate branches within the safety-related area.

Table 2-4 lists the schools identified within 8.0 km (5 mi) of the proposed site, the directional sector and distance band within which each school is located, and the best available estimate of the total number of students at that location. MU is located in several of the distance/direction sections. For the enrollment estimate, the percentage of the university's area that falls, either partially or entirely, within that segment was calculated using ArcMap 10 GIS software (ESRI, 2011). The equivalent proportion of university's enrollment was then assigned to that segment.

Table 2-4. Schools (2 pages)

Facility	Directional sector	Distance band (km)	Enrollment
Fr. Tolton Catholic High School (2013)	WSW	1 to 2	233
New Haven	NW	1 to 2	329
Bryan University	NW	2 to 4	331
Cedar Ridge	N	2 to 4	196
William Woods University	NW	2 to 4	1,036
Christian Chapel Academy	WNW	4 to 6	153
Columbia Career Center	W	4 to 6	43
Country Day School	WSW	4 to 6	150
Gentry Middle School	W	4 to 6	787
Rock Bridge	WSW	4 to 6	524
Rock Bridge High School	W	4 to 6	1,820
Sheppard Boulevard	NNW	4 to 6	504
University of Missouri[a]	NW	4 to 6	12,731
University of Missouri[a]	WNW	4 to 6	2,458
University of Missouri[a]	NNW	4 to 6	8
Benton	NNW	6 to 8	244
Children's House of Columbia	NW	6 to 8	80
Columbia College	NW	6 to 8	2,614
Columbia Independent	NW	6 to 8	230
Columbia Independent School	NW	6 to 8	117
Douglass High School	NW	6 to 8	144
Field	NNW	6 to 8	257

Table 2-4. Schools (2 pages)

Facility	Directional sector	Distance band (km)	Enrollment
Grant	NW	6 to 8	304
Islamic School of Columbia	NW	6 to 8	54
Jefferson Junior High	NW	6 to 8	812
Lee	NW	6 to 8	305
Stephens College	NNW	6 to 8	1,029
Stephens College Children's School	NNW	6 to 8	93
University of Missouri[a]	NW	6 to 8	13,180
University of Missouri[a]	WNW	6 to 8	6,368
Total			**46,751**

Sources: CHM, 2013; Columbia College, 2013; ISCM, 2013; MDE, 2013; Movoto, 2013; MU, 2013; NCES, 2013; New America Foundation, 2013; School Digger, 2013; and US News, 2013.

[a] The total University of Missouri enrollment (34,748) is proportional to the area of the University of Missouri that lies within the distance/direction sector based on the area.

Table 2-5 lists the medical facilities (hospitals and nursing homes) identified within 8 km (5.0 mi) of the proposed RPF site, the directional sector and distance band within which each facility is located, and the best available estimate of the total in-patient capacity (number of licensed beds) at that location. Medical facilities that do not have licensed beds (out-patient facilities) for patients to reside for more than one day were not included in the transient population estimate because visitations for these facilities are temporary (less than 8 hr/day).

Table 2-5. Medical Facility

Facility	Directional sector	Distance band (km)	Licensed beds
Lenoir Manor	WNW	1 to 2	84
Tiger Place	NW	2 to 4	112
Lenoir Health Care Center	NW	2 to 4	122
The Bluffs	NW	2 to 4	132
Columbia Manor Care	WNW	2 to 4	52
Bluff Creek Terrace	NW	2 to 4	52
Neighborhoods Rehabilitation and Skilled Nursing	NW	2 to 4	120
Boone Hospital Center	NNW	6 to 8	400
Landmark Hospital	NNW	6 to 8	42
University Hospital and Clinics	NW	6 to 8	383
Women's and Children's Hospital[a]	N	6 to 8	190
Daybreak Residential Treatment Center	NW	6 to 8	14
Harambee House, Inc.	NW	6 to 8	15
Columbia Healthcare Center	NNW	6 to 8	97
Harry S Truman Memorial Veterans	NW	6 to 8	126

Source: DHSS, 2013, "DHSS Community Data Profiles – Hospital Revenues from 2010-2012," http://health.mo.gov/data/CommunityDataProfiles/index.html, Missouri Department of Health & Senior Services, Jefferson City, Missouri, accessed September 5, 2013.

[a] In 2010, Columbia Regional Hospital became Women's and Children's Hospital.

Table 2-6 lists lodging facilities (hotels and motels) identified within 8 km (5.0 mi) of the proposed site, the directional sector and distance band within which each facility is located, and the best available estimate of the lodging capacity (number of rooms) at that location.

Table 2-6. Lodging Facilities

Facility	Directional sector	Distance band (km)	Room
Courtyard by Marriott	NW	2 to 4	125
Hampton Inn & Suites	NW	4 to 6	134
Stoney Creek Inn & Conference Center	WNW	4 to 6	181
Candlewood Suites	N	6 to 8	81
Baymont Inn & Suites	N	6 to 8	65
Country Inn & Suites	N	6 to 8	85
Fairfield Inn & Suites	N	6 to 8	91
Hampton Inn	N	6 to 8	120
Holiday Inn East	NNE	6 to 8	126
Ramada Inn & Suites	NNW	6 to 8	89
Residence Inn	N	6 to 8	80
Staybridge	N	6 to 8	82
Super 8	N	6 to 8	75
Super 8 East	NNE	6 to 8	56
The Gathering Place	NW	6 to 8	5
The Tiger Hotel	NW	6 to 8	62
University Ave Bed & Breakfast	NW	6 to 8	4
Wingate	N	6 to 8	81

Sources:

Columbia Convention and Visitors Bureau, 2013, "Where to stay- Hotels, Inns, and Motels," http://www.visitcolumbiamo.com/section/stay/, Columbia, Missouri, accessed September 9, 2013.

Cvent, 2013, "Hotels near Columbia MO," http://www.cvent.com/RFP/Venues.aspx?ist=6&ma= 97&csn=1&vtt=1#page-6&so-1, Cvent Supplier Network, Tysons Corner, Virginia, accessed September 9, 2013.

The estimates provided in Table 2-7 represent the total number of people expected to be at each facility for any part of the day, with no consideration of the length of time they are likely to be there. The anticipated growth of Discovery Ridge may be underestimated using the above methodology. Developers are planning for an additional 1,000 employees supporting research at the park over the next 20 years (MMRPC, 2015). To account for this potential grow, an additional 30 new transient personnel are assumed to be employed near Discovery Ridge each year starting in 2020. This increase is spread equally between sectors over the estimating period.

To more accurately represent the transient population around the proposed site, the values in Table 2-7 were weighted according to the length of time people could be expected to stay at each facility, assuming typical use patterns for that type of facility. The estimates for employers and schools were multiplied by a weighting factor of 0.27, which assumes that each employee or student is present at the facility 9 hr/day, 5 days/week. The estimates for medical facilities were multiplied by a weighting factor that was determined by the specific use. For hospitals/clinics, the known occupation rate for each facility was multiplied by the number of licensed beds, which assumes at any one time a percentage of the beds are in use (DHSS, 2013).

Nursing homes were not multiplied by any weighting factor, effectively assuming that each available room is occupied 24 hr/day and 7 days/week. The estimates for lodging facilities in the city of Columbia were multiplied by the average occupancy rate (60 percent) (Reed, 2010).

Table 2-7. Weighted Transient Population Estimates by Source

Distance band (km)	Major employers[a]	Schools[a]	Medical facilities (hospitals and assisted living)	Lodging (hotels and motels)	Totals
0 - 1	162	0	0	0	162
1 - 2	45	152	84	0	281
2 - 4	722	423	590	75	1,810
4 - 6	1,260	5,184	0	189	6,633
6 - 8	4,011	6,982	804	661	12,458
0 -8 (Total)	**6,200**	**12,741**	**1,478**	**925**	**21,344**

[a] Updated to include new employers and schools as of June 2017.

The weighted 2010 transient population estimates calculated for each type of facility in each distance band area summarized in Table 2-7. Figure 2-15 shows the weighted 2010 transient population estimates divided into the distance/direction segments.

Using the same population projection methodologies used for resident populations, the 2010 transient population estimates within the distance bands and directional sectors were extrapolated to the years 2014, 2015, 2019, 2020, 2045, and 2050. Table 2-8 shows the total projected transient population for these years within the distance bands, and Figure 2-15 through Figure 2-21 show the population projections for these years divided into the distance/direction segments.

Table 2-8. Total Project Transient Population

Year	Distance Band (km)					
	0 – 1	1 – 2	2 – 4	4 – 6	6 – 8	Total 0 – 8
2010	94	207	1,807	6,633	12,452	**21,193**
2014	100	395	1,912	7,033	13,207	**22,647**
2015	101	397	1,944	7,140	13,406	**22,988**
2019	107	486	2,060	7,566	14,210	**24,429**
2020	117	494	2,091	7,680	14,424	**24,798**
2045	341	657	2,562	9,426	17,669	**30,447**
2050	391	714	2,755	10,125	18,995	**32,732**

[a] Includes Fr. Tolton Catholic High School and the Central Regional Conservation Office starting in 2013.

[b] Includes Discovery Office Park starting in 2016.

[c] Includes employment growth at Discovery Ridge Research Park starting 2020.

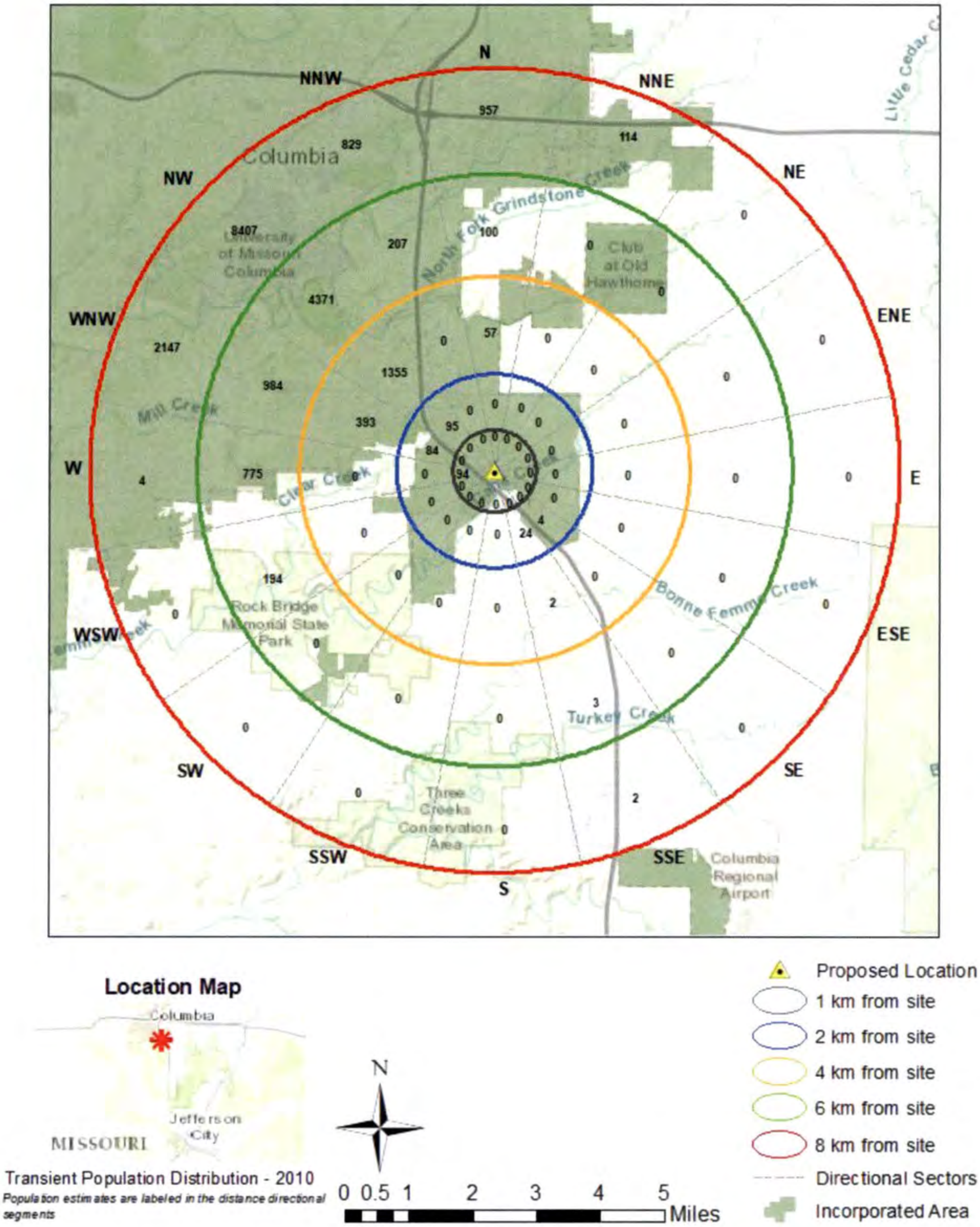

Figure 2-15. Transient Population Distribution – 2010

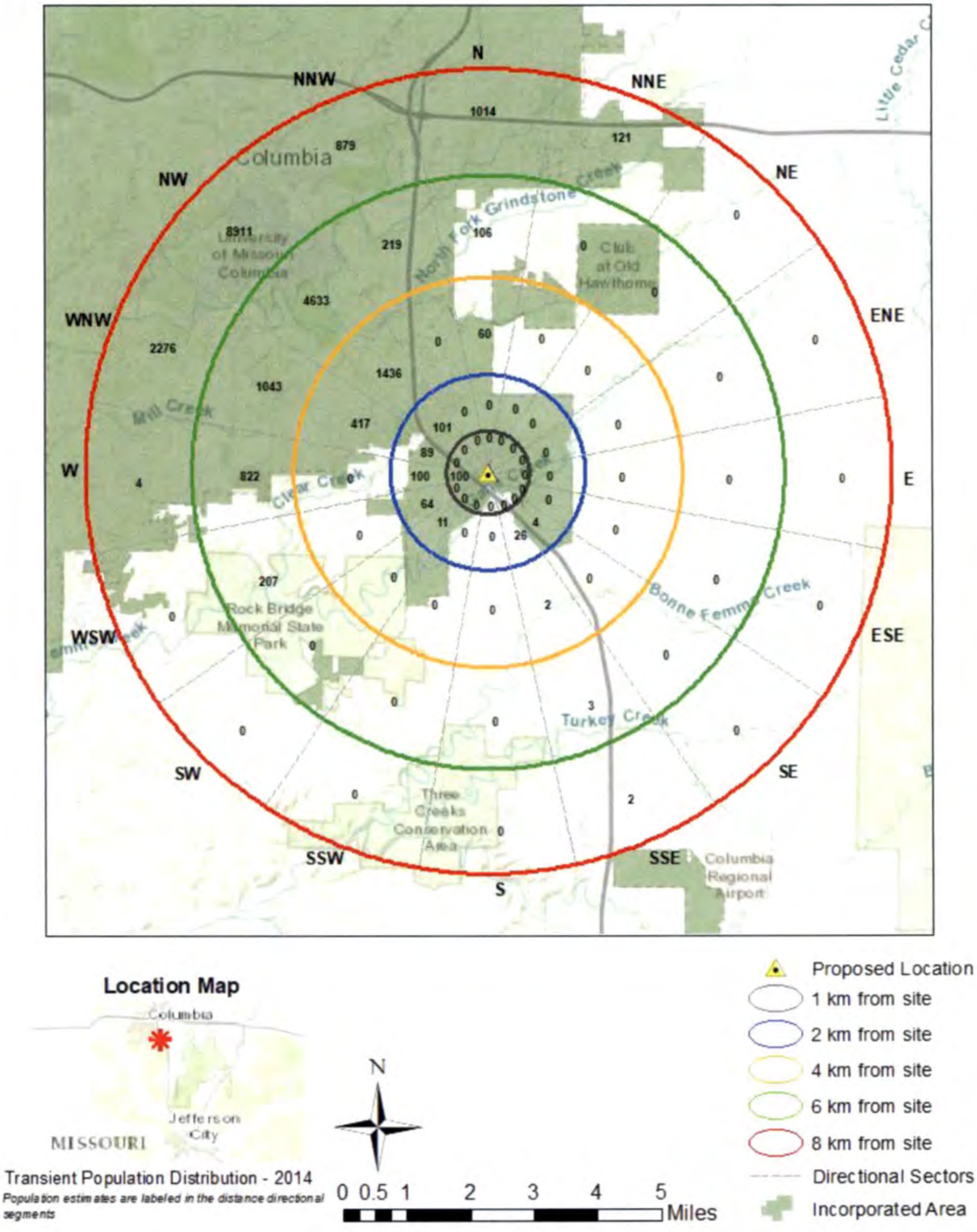

Figure 2-16. Transient Population Distribution – 2014

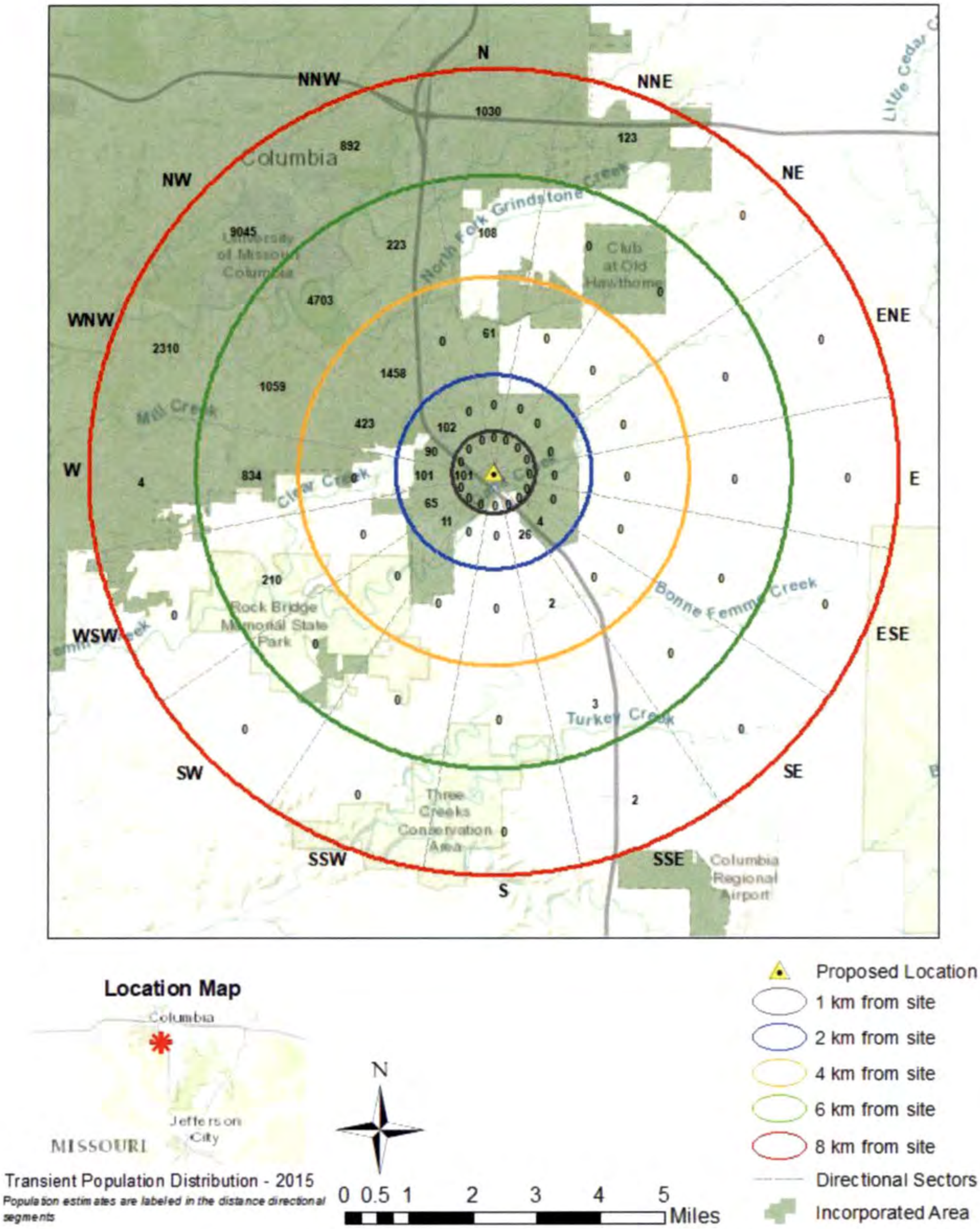

Figure 2-17. Transient Population Distribution – 2015

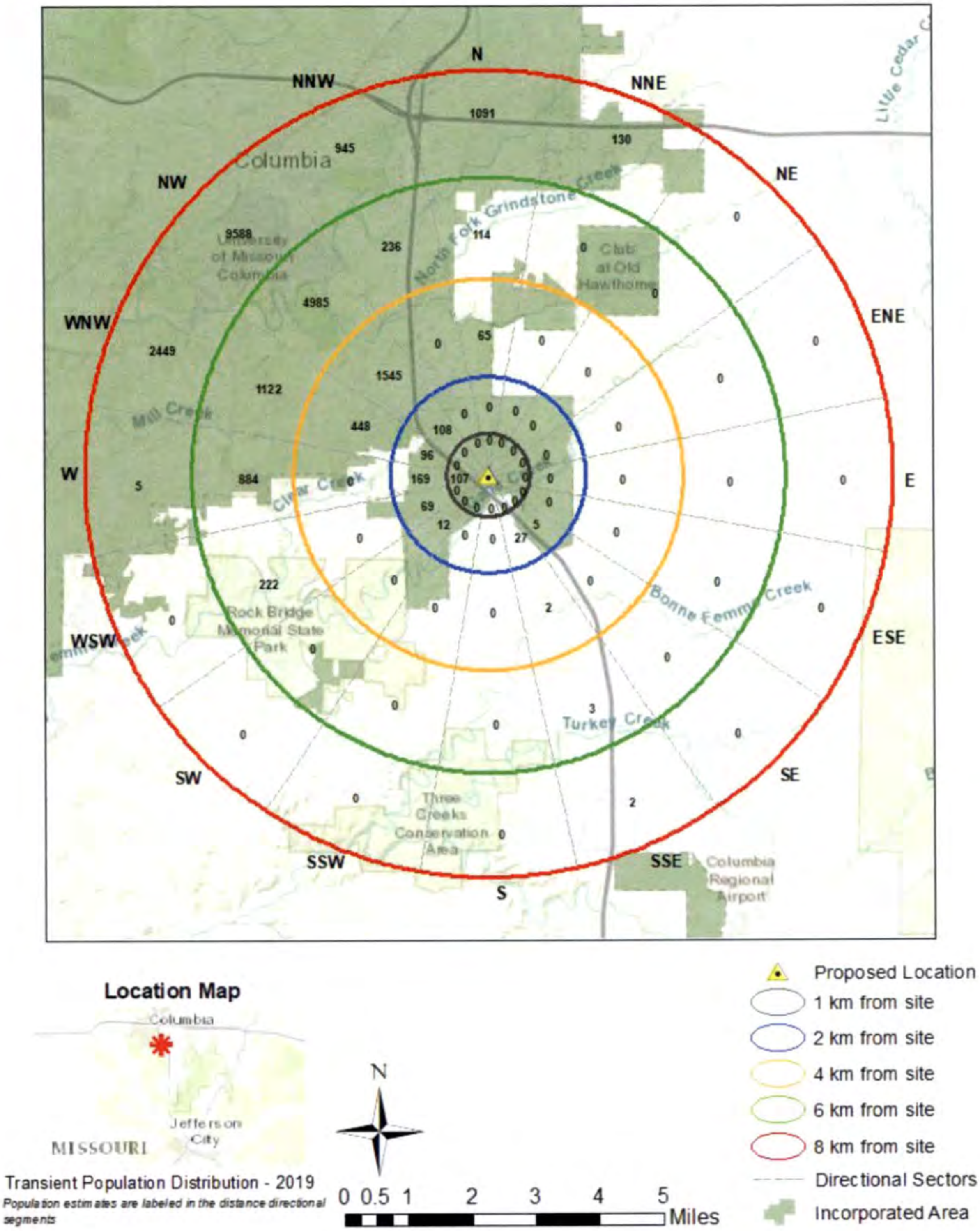

Figure 2-18. Transient Population Distribution – 2019

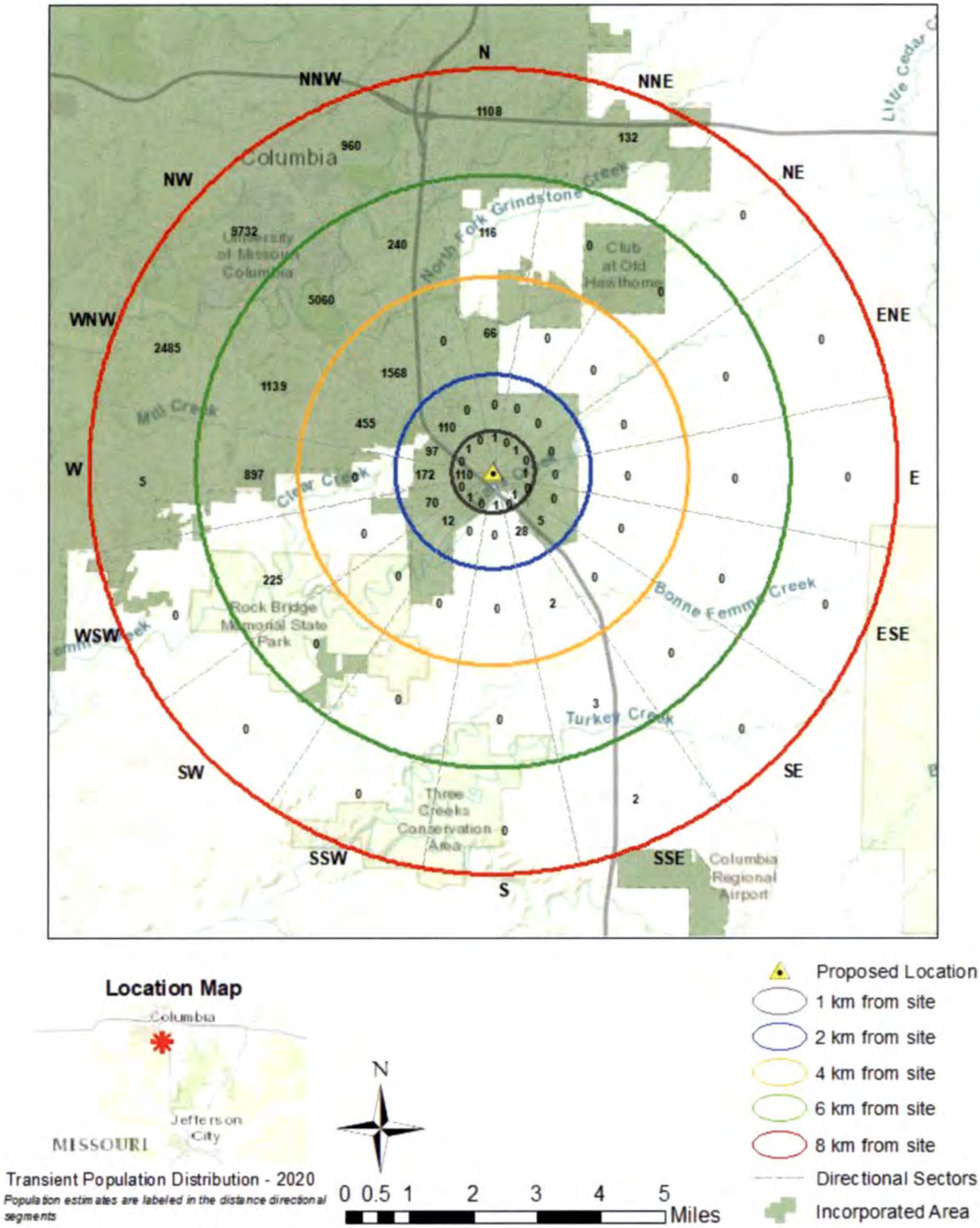

Figure 2-19. Transient Population Distribution – 2020

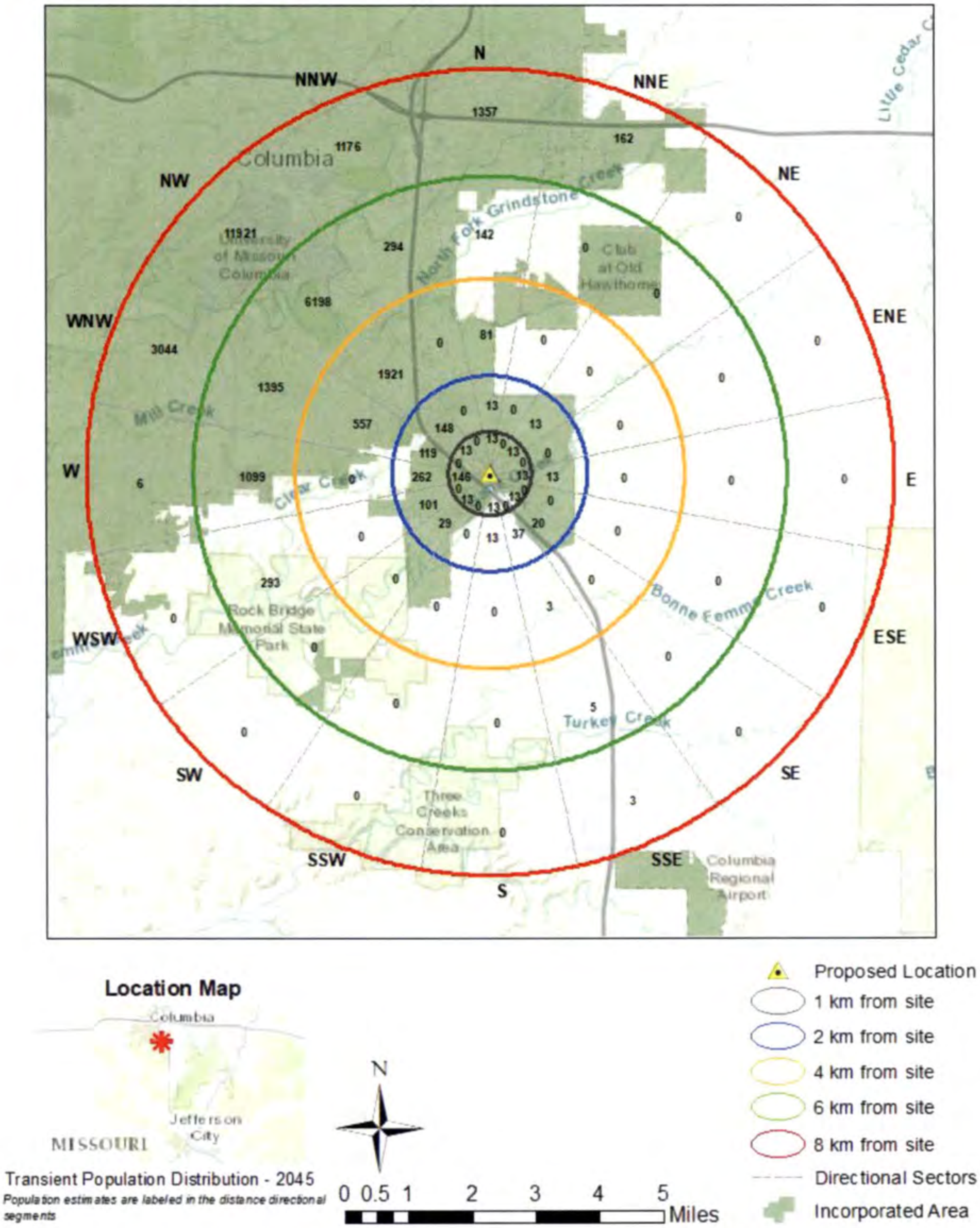

Figure 2-20. Transient Population Distribution – 2045

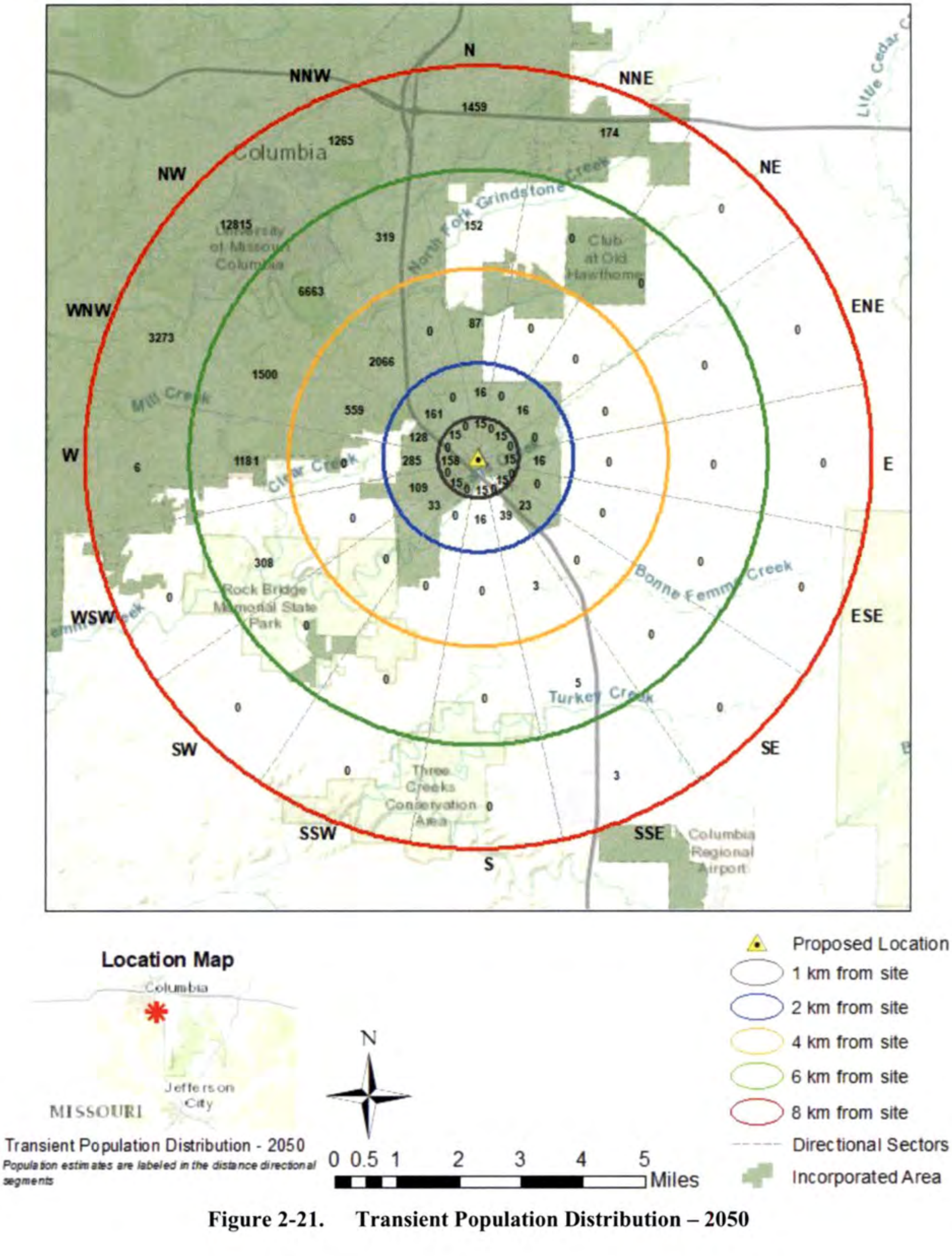

Figure 2-21. Transient Population Distribution – 2050

2.1.3 Combined Resident and Transient Population

The estimated 2010 and projected future resident and transient population values were summed to obtain an indication of the effective total population around the project site. Table 2-9 summarizes the combined resident and transient population values for all the years within the distance bands, and Figure 2-22 through Figure 2-28 show that combined populations for all years divided into the distance/directional segments.

Table 2-9. Combined Resident and Transient Population

Year	Distance band (km)					
	0 – 1	1 – 2	2 – 4	4 – 6	6 – 8	Total 0 – 8
2010	299	2,069	8,877	23,553	33,968	**68,766**
2014	318	2,367	9,402	24,969	36,008	**73,064**
2015	322	2,401	9,552	25,345	36,549	**74,169**
2019	341	2,610	10,122	26,862	38,740	**78,675**
2020	355	2,650	10,275	27,265	39,321	**79,858**
2045	632	3,282	12,553	33,374	48,097	**97,730**
2050	704	3,534	13,482	35,853	51,679	**105,004**

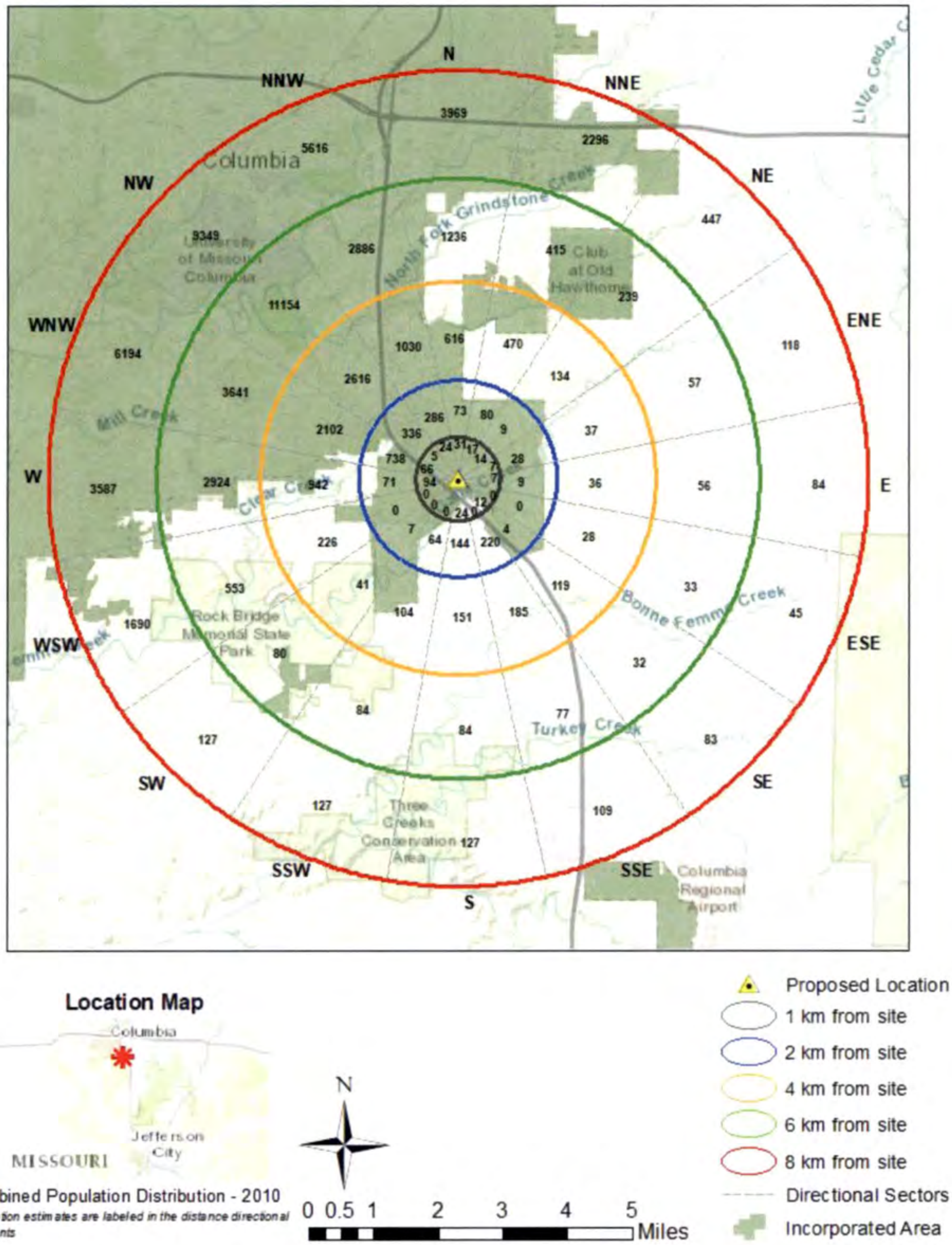

Figure 2-22. Combined Population Distribution – 2010

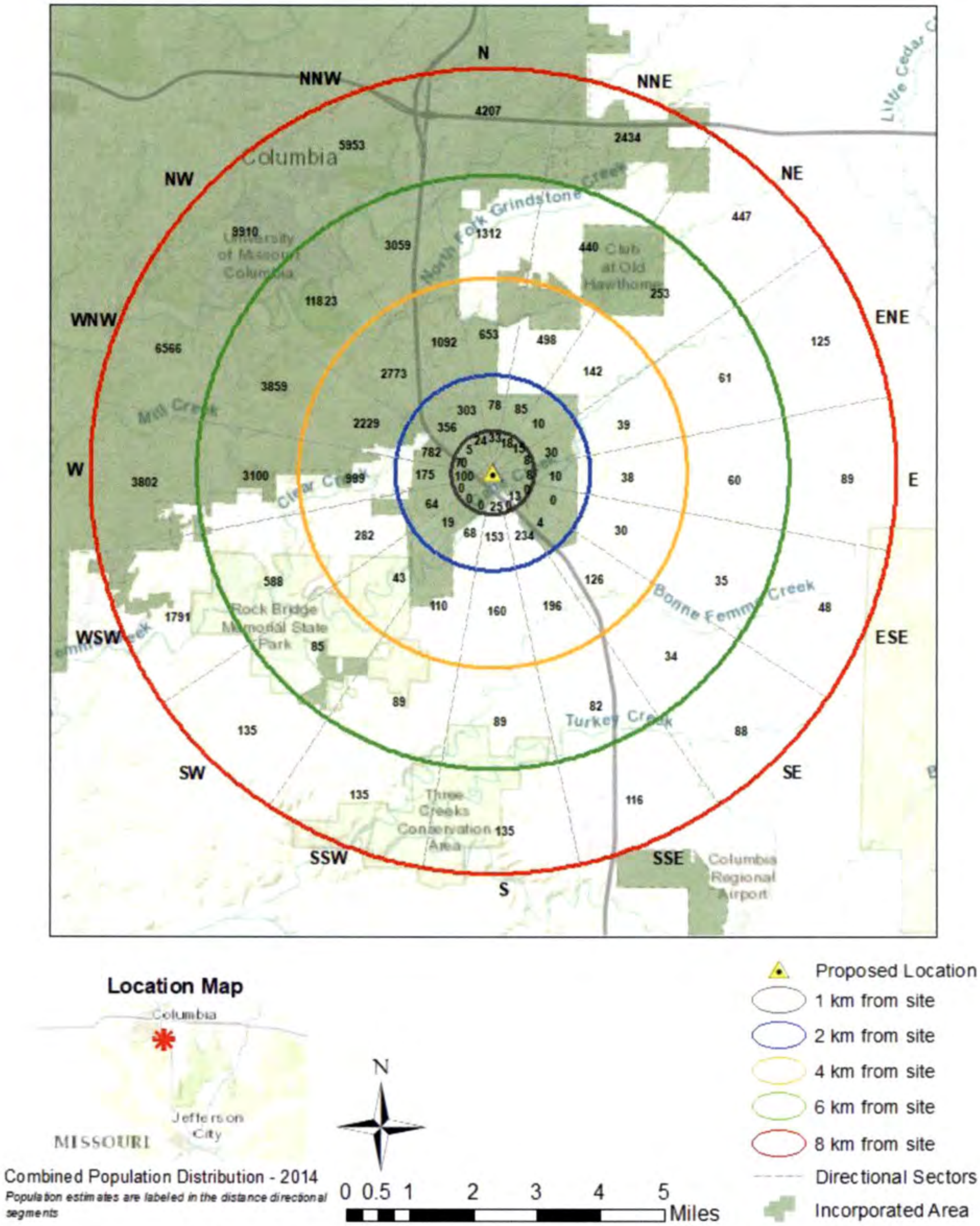

Figure 2-23. Combined Population Distribution – 2014

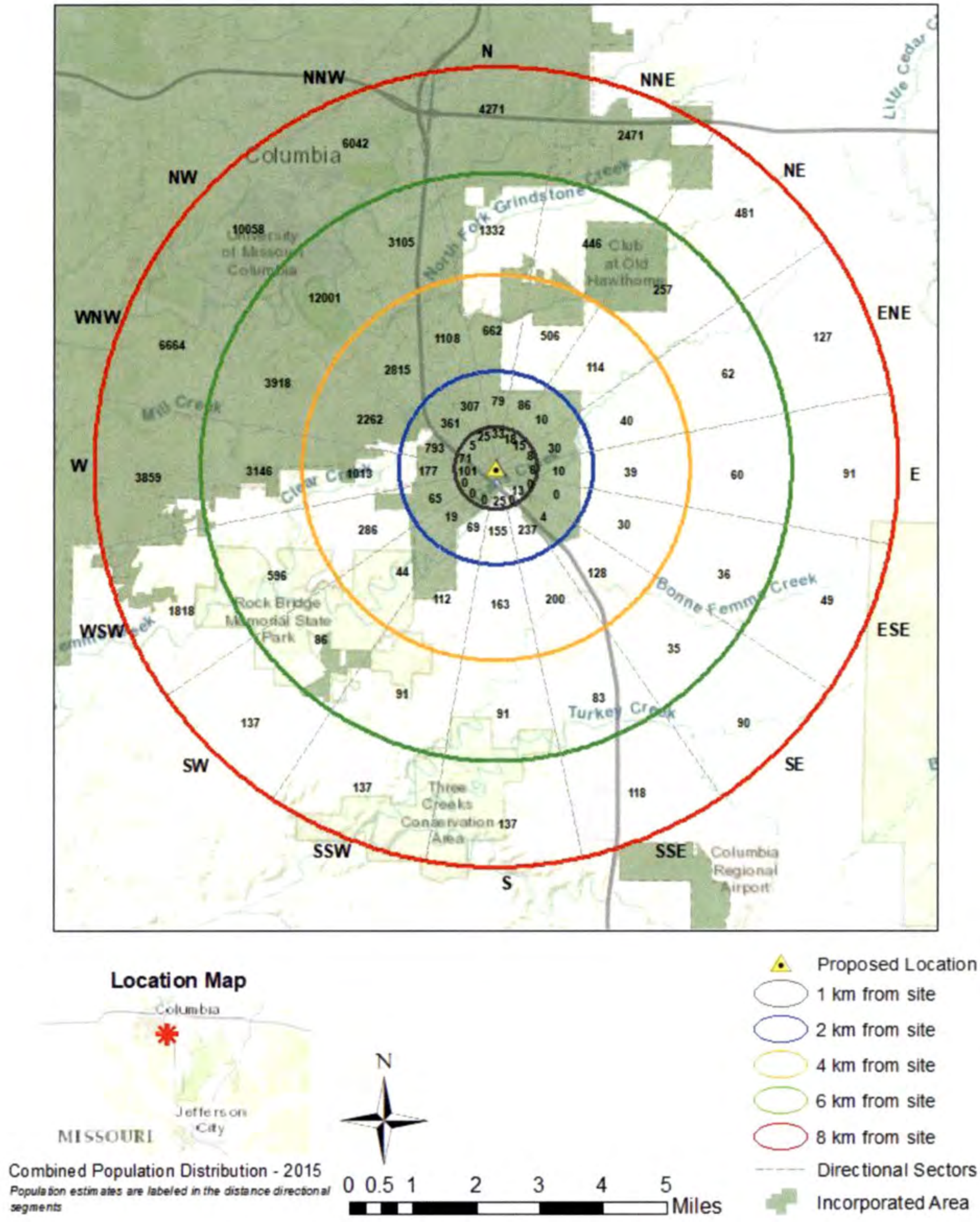

Figure 2-24. Combined Population Distribution – 2015

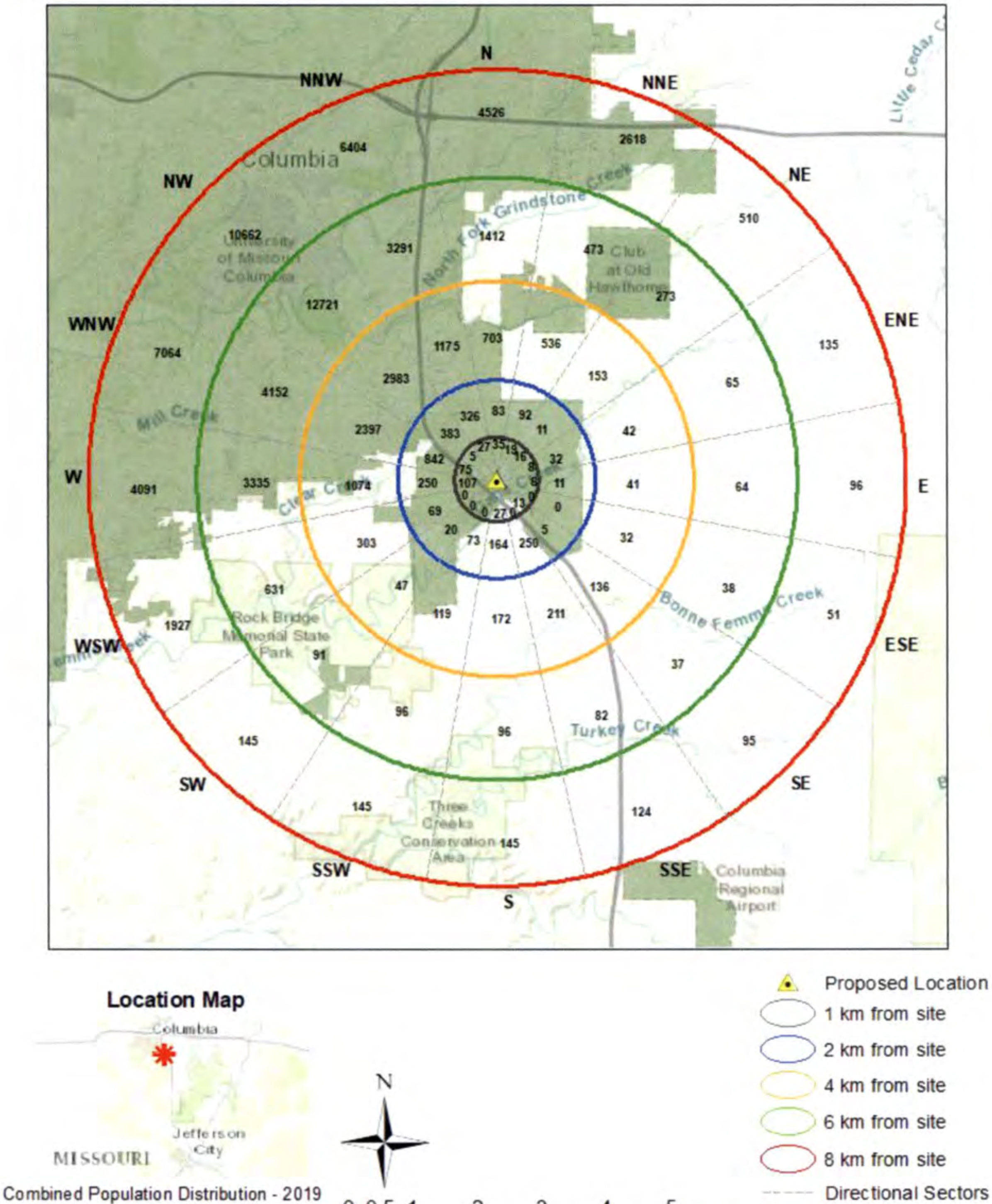

Figure 2-25. Combined Population Distribution – 2019

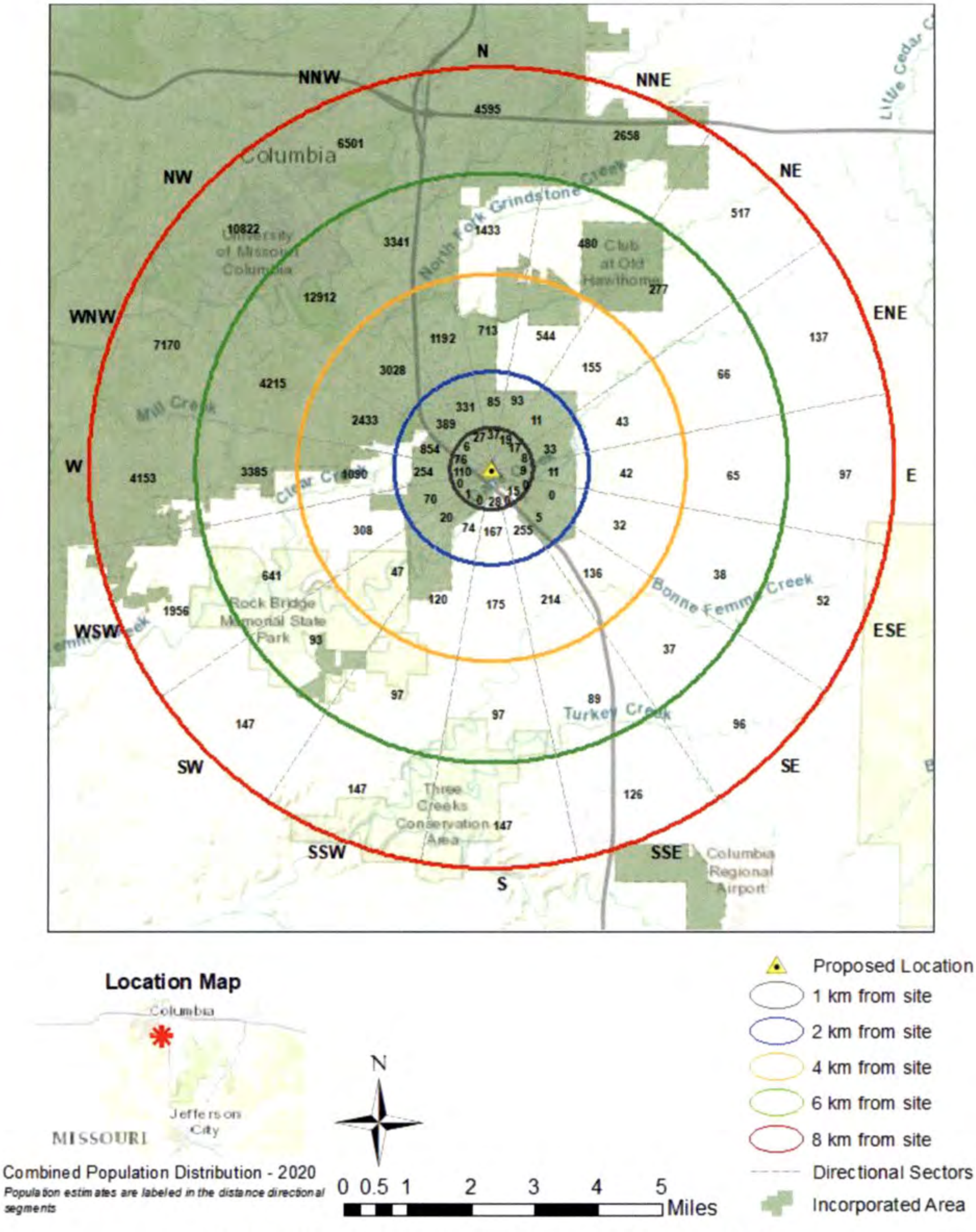

Figure 2-26. Combined Population Distribution – 2020

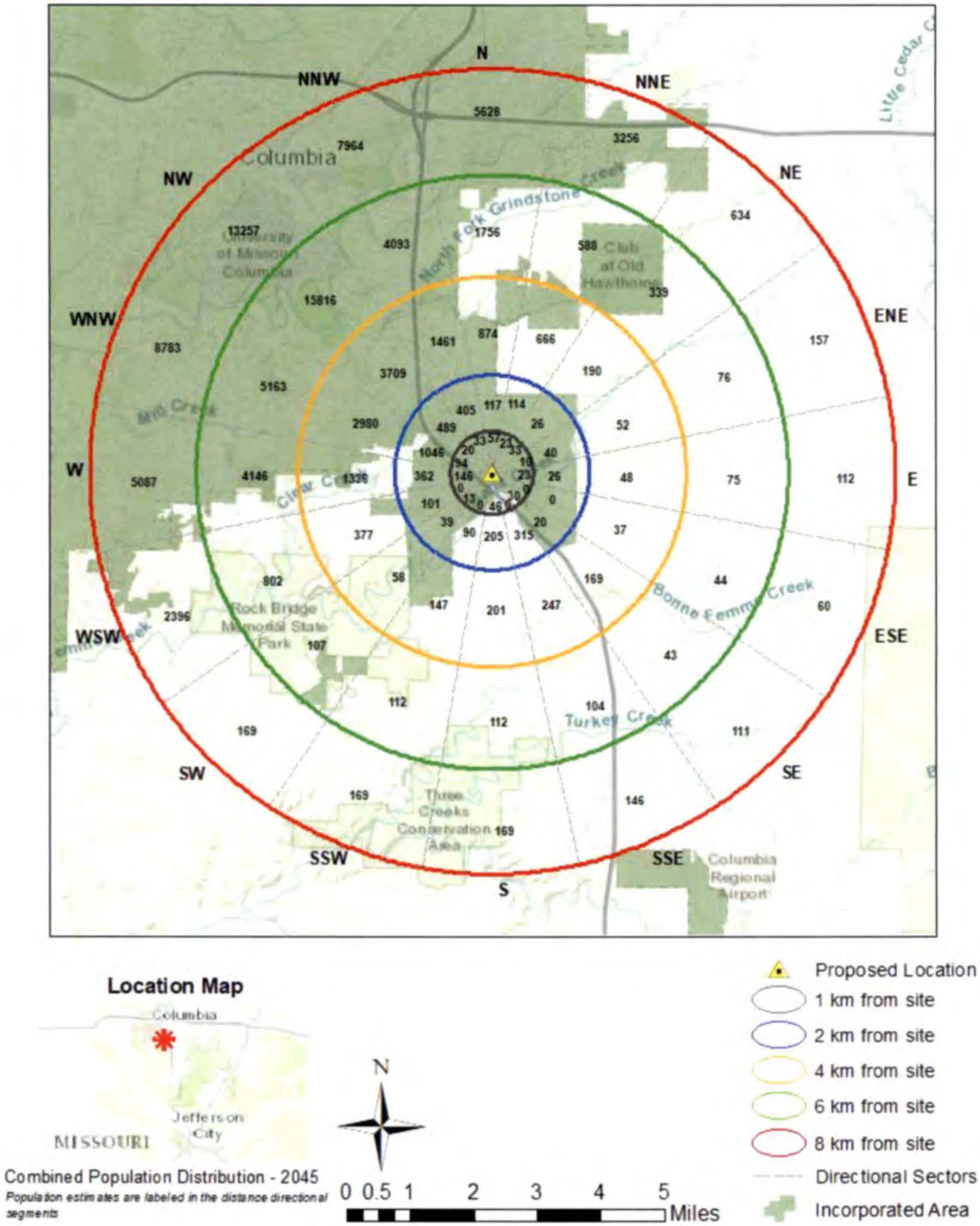

Figure 2-27. Combined Population Distribution – 2045

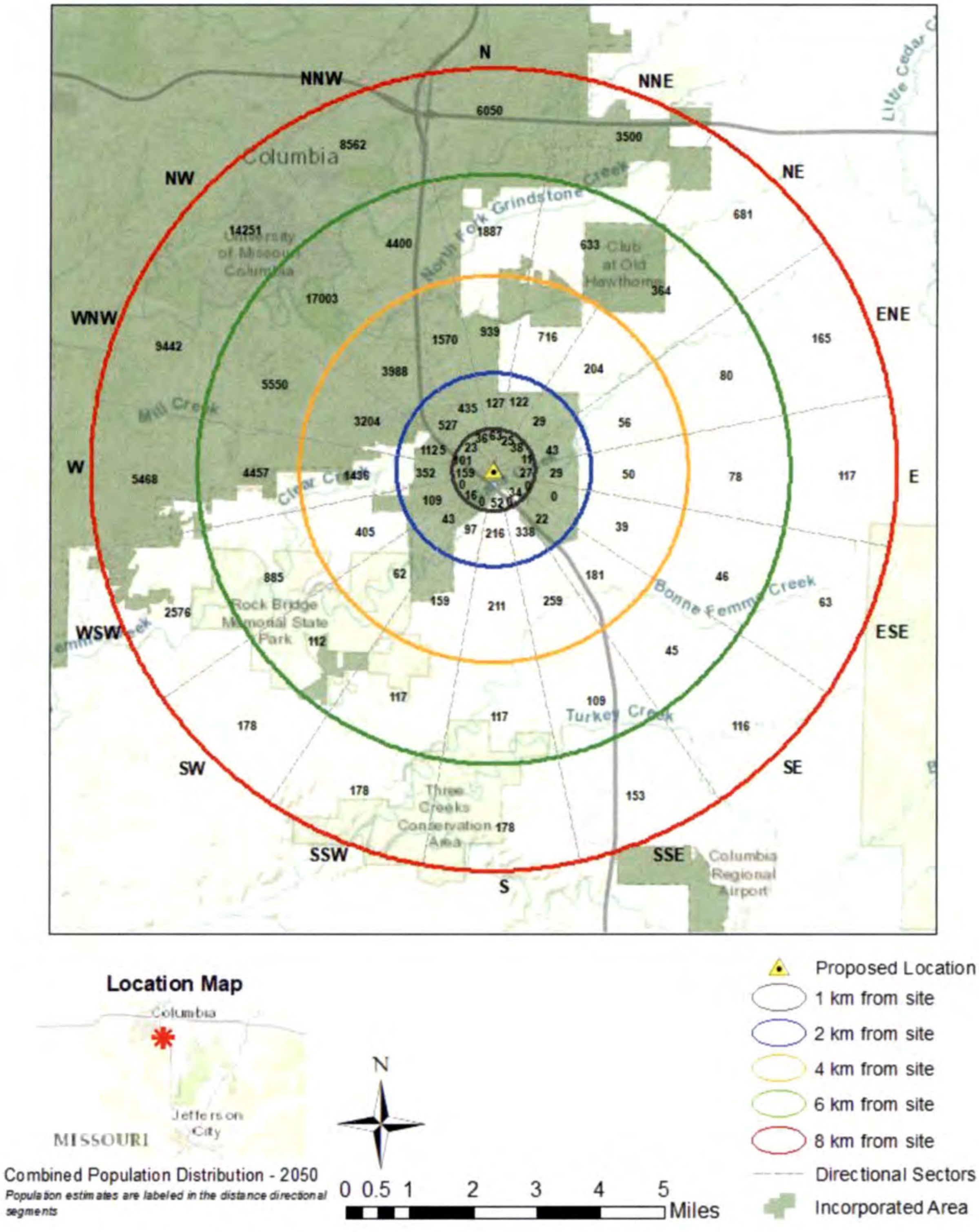

Figure 2-28. Combined Population Distribution – 2050

2.2 NEARBY INDUSTRIAL, TRANSPORTATION, AND MILITARY FACILITIES

This section identifies and evaluates present and projected future industrial, transportation, and military installations and operations in the area within 8 km (5 mi) of the RPF site. In addition, facilities and activities at a greater distance than 8 km (5 mi) are also considered as appropriate to their significance.

2.2.1 Location and Routes

Access to the proposed RPF site is from Discovery Ridge Drive. The site is situated in central Missouri, approximately 201 km (125 mi) east of Kansas City and 201 km (125 mi) west of St. Louis. The site is 7.2 km (4.5 mi) south of U.S. Interstate 70, just north of U.S. Highway 63. The Missouri River lies 15.3 km (9.5 mi) west of the site. The site is located 5.6 km (3.5 mi) southeast of the main MU campus.

An investigation of industrial, transportation and military facilities within 5 mi (8 km) of the proposed site was performed. The U.S. Environmental Protection Agency's Envirofacts Database was initially used to identify potential facilities within 8 km (5 mi). The Missouri Emergency Management Agency supplied Tier II chemical inventory reports for all of the facilities in Boone County. The following facilities were identified for further evaluation.

Industrial Facilities

- Analytical Bio Chemistry Laboratories, Inc.
- Radil Discovery Ridge
- Gates Power Transmissions Materials Center
- MU South Farm
- MU Woman's and Children's Hospital
- Ryder Transportation
- Truegreen
- Schwan's Home Service
- Petro Mart #44

Pipelines

- Southern Star Central Gas – Natural Gas Transmission Pipeline
- Magellan Pipeline Company – Non-HLV product Hazardous Pipeline
- Magellan Pipeline Company – Liquid Hazardous Pipeline
- Ameren Natural Gas – Transmission Pipeline #1
- Ameren Natural Gas – Transmission Pipeline #2

Fuel Storage Facilities

- Magellan Pipeline Company – Breakout Tank

Transportation Routes/Facilities

- Heliports
  - University of Missouri heliport
  - Boone Hospital Center heliport
- Land
  - U.S. Highway 63
  - U.S. Interstate 70
  - State Route 163
  - State Route 740
  - State Route 763
- Waterways – None
- Railroads – COLT Transload

Military Bases

- None

Mining and Quarrying Operations

- None

Figure 2-29 shows the location of the transportation and industrial facilities identified within 8 km (5 mi) of the proposed RPF site.

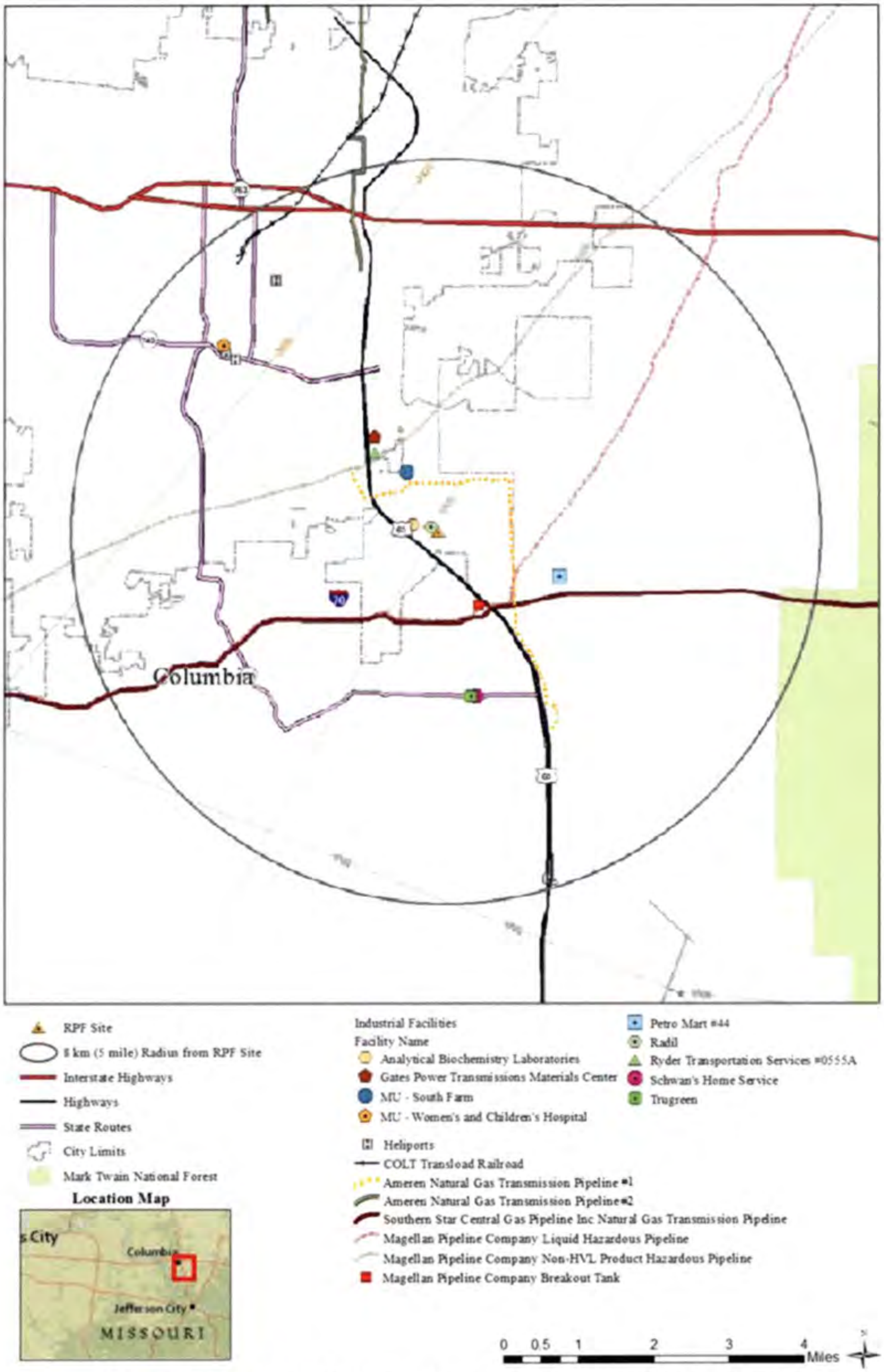

Figure 2-29. Industrial and Transportation within 8 km (5 mi) of the Radioisotope Production Facility Site

An investigation of industrial, military, and transportation facilities from 8 km to 16 km was also conducted and identified the following transportation facilities for further evaluation. Figure 2-30 shows the airports, jet routes, and airway routes within 16 km (10 mi) of the proposed RPF site.

Industrial Facilities

- 3M Company – Columbia
- AT&T, Inc.
- Columbia Municipal Power
- MPC #93

Major Waterways

- Missouri River

Pipelines

- Panhandle Eastern Pipeline Company – Natural Gas Transmission Pipeline

Airports

- Sugar Branch Airport
- Cedar Creek Airport
- Columbia Regional Airport

Fuel Storage Facilities

- Midway Auto Truck plaza
- Ballenger Propane, Inc.
- Ferrellgas

2.2.1.1 Future Facilities

A review was conducted to identify potential future facilities and transportation routes (e.g., industrial growth) that if established or constructed, could have an adverse effect on the RPF. These future facilities/routes were identified through several sources. The initial lists of local projects were identified using the City of Columbia comprehensive land use plan (City of Columbia, 2013). State and county planning documents were also reviewed, and potential projects were discussed with Regional Economic Development, Inc., to identify potential private facilities. The majority of projects identified in the City of Columbia comprehensive land use plan are infrastructure-type projects of a nature that would exclude potential accidents that could affect the RPF.

Two new projects were identified that may be constructed near the Discovery Ridge, including:

- **Global PET Imaging Facility** – The proposed facility is being designed and constructed to process rubidium-82 (^{82}Rb) using a 70-million electron volt (MeV) cyclotron. This facility, along with any other potential facilities that might be constructed within the Discovery Ridge, are assumed to be similar in nature to the existing facilities and RFP with similar potential hazards. As such, accidents associated with future facilities are assumed to be similar to those currently at Discovery Ridge and are bounded within the current accident analysis.
- **Odles' Discovery Park (residential/commercial development)** – Proposed development would be located approximately 0.8 km (0.5 mi) west of Discovery Ridge. The development is currently planned as a housing development intermixed with commercial shops and businesses. These commercial facilities are not anticipated to store large quantities of hazardous or flammable materials and would not likely pose a hazard to the RPF.

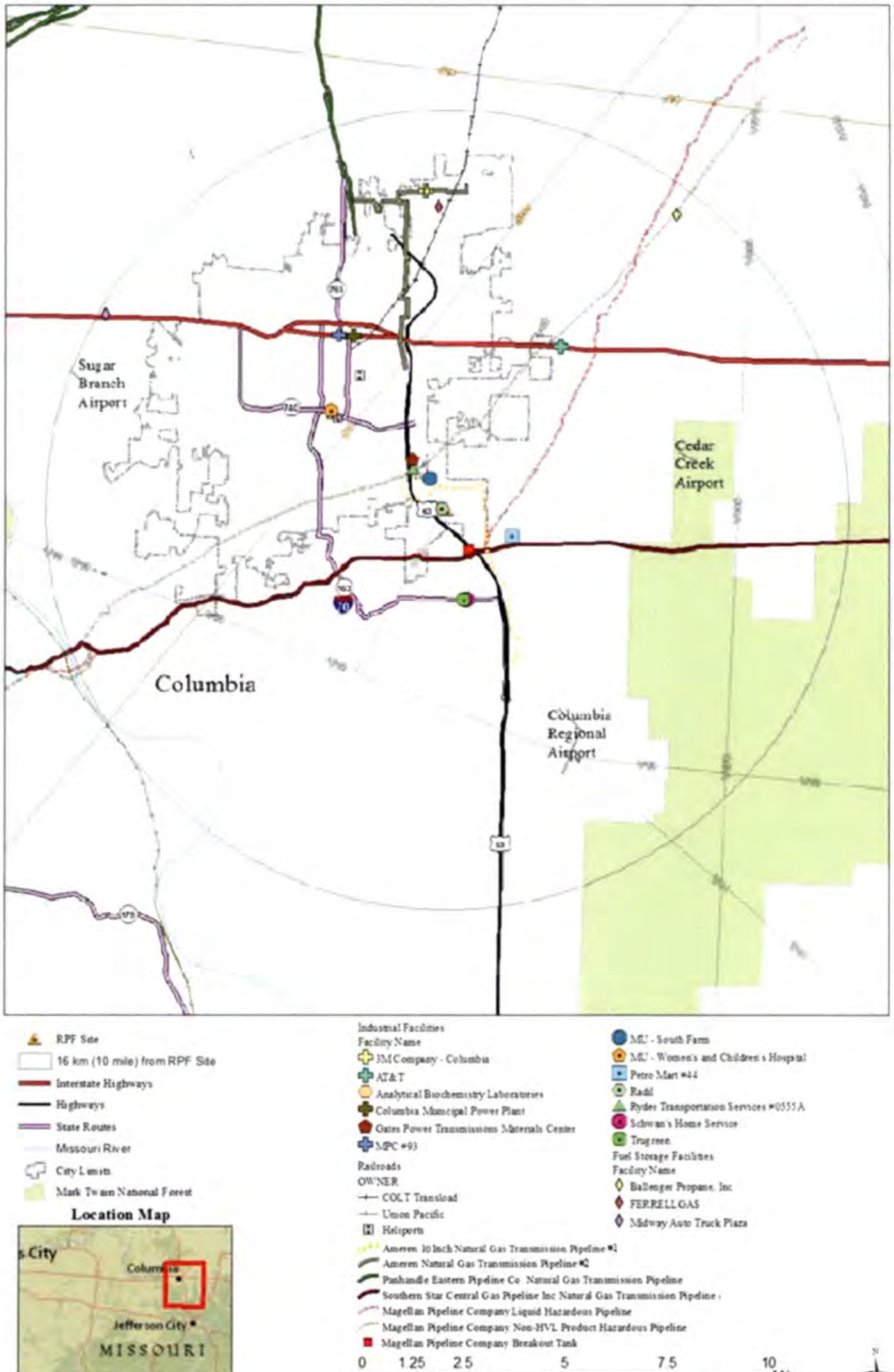

Figure 2-30. Industrial and Transportation within 16 km (10 mi) of the Radioisotope Production Facility Site Descriptions

2.2.1.2 Industrial Facilities

Descriptions of the industrial and transportation facilities identified within the 8 km (5-mi) radius of the RPF are provided below. For those facilities identified for future investigation, the Tier II reports were evaluated to determine if the facility used or stored large amounts of hazardous materials that could have a potential impact on the RPF. Of the facilities identified in Figure 2-29, Table 2-10 provides a description of those facilities that were identified as having potentially hazardous materials onsite that could potentially affect the RPF. Table 2-10 provides a listing of these facilities, including their primary functions and major products, and the hazardous materials onsite. A detailed analysis was conducted of the potential accidents at these facilities and potential hazards and impacts to the proposed RPF.

Table 2-10. Significant Industrial Facilities within 16 km (10 mi) of the Radioisotope Production Facility Site

Facility	Product	Distance from RPF		Direction	Hazardous material
		km	mi		
Gates Power Transmissions Materials Center	Vehicle and machinery drive belts	2.4	1.5	Northwest	• [Proprietary Information] • [Proprietary Information]
MU South Farm	Agriculture	1.6	1	Northwest	• [Proprietary Information] • [Proprietary Information] • [Proprietary Information] • [Proprietary Information]
Ryder Transportation	Rental trucks	2.4	1.5	South	• [Proprietary Information]
3M Company	Electronic components	12.9	8	North	• [Proprietary Information]
Schwan's Home Service	Food service	6.8	2.4	South	• [Proprietary Information]

MU = University of Missouri. RPF = Radioisotope Production Facility

2.2.1.3 Transportation Routes

U.S. Highway 63 runs approximately 0.4 km (0.25 mi) south of the RPF site. U.S. Highway 63 proceeds north and intersects U.S. Interstate 70 approximately 7.64 km (4.75 mi) to the north. U.S. Highway 63 continues to Jefferson City, Missouri, approximately 50 km (31 mi) to the south.

Other highways within the 8 km (5-mi) radius of the proposed RPF site include State Highway 63 that intersects U.S. Highway 63 3.2 km (2 mi) south of the RPF and routes north approximately 4.8 km (3 mi) west of the RPF. State Highway 740 intersects U. S. Highway 63 approximately 3.7 km (2.3 mi) north of the RPF, and routes west. State Highway 763 intersects State Highway 740 5.3 km (3.3 mi) north of the RPF and routes north to U.S. Interstate 70.

Information is not available about the materials transported on the roads in the vicinity of RPF site. To better understand the materials that could be transported over these roads, Superfund Amendments and Reauthorization Act (SARA) Title III, Tier II reports for industrial facilities within 8 km (5 mi.) of the RPF site were consulted.

The Missouri's Commercial Vehicle Regulations (MoDOT, 2013) provided the maximum gross vehicle weight of 36,290 kilogram (kg) (80,000 pounds [lb]). Using the assumption that an average truck and trailer combination weighs 13,600 kg (30,000 lb), the allowable weight that a truck could carry on the highways would be 22,690 kg (50,000 lb).

For analysis, all materials were assumed to travel on State Highway 63, 0.4 km (.25 mi) south of the RPF. Table 2-11 summarizes the chemicals and anticipated amounts that are present at the industrial facilities that could pose a hazard when transported.

Table 2-11. Hazardous Chemical Potentially Transported on Highways within an 8 km (5-mi) Radius of the Radioisotope Production Facility

Hazardous material	Quantity	
	kg	lb
Ammonia	22,680	50,000
Ammonium nitrate	22,680	50,000
Chlorine	408	900
Diesel	22,680	50,000
Gasoline	22,680	50,000
Glycol ether PM	22,680	50,000
Hydrofluorosilicic acid	22,680	50,000
Hydrogen	1,497	3,300
JP-4 aviation fuel	22,680	50,000
Methyl ethyl ketone	22,680	50,000
Oil	22,680	50,000
Pentaerythritol distearate	22,680	50,000
Petroleum naphtha	22,680	50,000
Propane	22,680	50,000
Sulfur dioxide	22,680	50,000
Toluene (32-8413)	22,680	50,000
Zetpol (all types)	22,680	50,000

2.2.1.4 Pipelines

Several natural gas distribution pipelines are located within 8 km (5 mi) of the proposed RPF site, as depicted in Figure 2-29. Available information about these pipelines is included in Table 2-12.

Ameren Missouri operates a natural gas transmission line approximately 6.0 km (4 mi) and a pipeline installed in 2016 approximately 0.64 km (0.4 mi) north of the proposed RPF site. Southern Star Central Gas Pipeline, Inc. operates a natural gas transmission pipeline located approximately 1.6 km (1 mi) south of the proposed site. Magellan Midstream Partners, LP operates two pipelines within 8 km (5 mi) of the site, including a pipeline 2.0 km (1.25 mi) to the north, which carries refined petroleum products. The company also maintains a recently reopened line approximately 1.6 km (1 mi) south of the proposed RPF site.

Table 2-12. Major Pipelines Located within 8 km (5 mi) of the Radioisotope Production Facility Site

Pipeline company	Product	Diameter		Pressure (max)		Distance from RPF		Direction
		cm	in.	kPa	lb/in.^{2}	km	mi	
Ameren Missouri	Natural gas (#1)	[Proprietary Information]						North
Ameren Missouri	Natural gas (#2)	[Proprietary Information]						North
Southern Star Central Gas Pipeline, Inc.	Natural gas	[Proprietary Information]						South
Magellan Midstream Partners, LP	Refined petroleum	[Proprietary Information]						North
Magellan Midstream Partners, LP	Refined petroleum	[Proprietary Information]						South/east

RPF = Radioisotope Production Facility.

2.2.1.5 Fuel Storage

Two major fuel storage facilities are located within the 8 km (5-mi) radius of the proposed RPF site, and include the Magellan Pipeline Company Breakout Tank and the Ferrellgas facility. Information of each of these facilities is provided in Table 2-13.

Table 2-13. Major Storage Facilities Located within 8 km (5 mi) of the Radioisotope Production Facility Site

Storage facility	Product	Volume (gal)	Distance from RPF		Direction
			km	mi	
Magellan Pipeline Company Breakout Tanks	[Proprietary Information]	[Proprietary Information]	1.6	1	Southeast
Ferrellgas	[Proprietary Information]	[Proprietary Information]	8	5	North

RPF = Radioisotope Production Facility.

2.2.2 Air Traffic

2.2.2.1 Airports

There are three airports and three helicopter ports located within 16 km (10 mi) of the proposed RPF site. The three airports include:

- Columbia Regional Airport (COU) (public) located approximately 10.4 km (6.5 mi) south of the RPF site
- Cedar Creek Airport (private) located approximately 10.6 km (6.6 mi) northeast of the RPF site
- Sugar Branch Airport (private) located approximately 15.6 km (9.7 mi) northwest of the RPF site

These airports are identified in Figure 2-30 (Section 2.2.1.1).

The nearest airport to the RPF is COU, which is used by commercial and privately owned aircraft. The airport is situated on approximately 532 ha (1,314 acres) and is owned and operated by the City of Columbia. This airport is the only public use airport located in Boone County, Missouri, for which records are kept. For January through December 2016, the airport had 21,894 (22,439, including overflights) aircraft operations (Parks, 2017a), including:

- 67.6 percent general aviation
- 17.7 percent air taxi
- 9.3 percent military
- 4.8 percent air carrier

Cedar Creek airport is a private, turf landing strip approximately 10.6 km (6.6 mi) northeast of the RPF site. The facility houses two private single engine aircraft. The specific number of flights to and from the facility is not available.

The Sugar Branch airport is a private, turf landing strip approximately 15.6 km (9.7 mi) northwest of the RPF site. The facility houses one single engine aircraft. The specific number of flights to and from the facility are not available.

Two helicopter ports are located within 16 km (10 mi) of the RPF site that support hospital operations. For calendar year 2016 (January through December), the heliports have a total of 654 flights annually, as follows:

- University of Missouri Hospital and Clinics located 6 km (3.7 mi) northwest – 308 flights (Jones, 2017)
- Boone Hospital Center heliport located 6.3 km (3.9 mi) northwest – 346 flights (Eidson, 2017)

Based on NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors - Format and Content*, sites located between 8 km (5 mi) and 16 km (10 mi) from an existing or projected commercial or military airport with more than approximately 200 d^2 (where d is the distance in kilometers from the airport to the RPF site) commercial or military aircraft movements per year, the probability of aircraft accidents is considered less than an order of magnitude of 10^{-7} per year.

The number of operations at the Cedar Creek and Sugar Branch airports are not available. However, daily operations were assumed based on the aircraft housed, including two operations per day from Cedar Creek (730 operations/year) and one operation per day from Sugar Branch (365 operations/year). Based on the results presented in Table 2-14, all three airports are under the 200 d^2 limits.

Table 2-14. 200 D2 Limits

Airport	Distance km (mi)	Flights per year	200 d^2 limits[a]
Columbia Regional Airport	10.4 (6.5 mi)	21,894	21,632
Cedar Creek	10.6 (6.6 mi)	730	22,472
Sugar Branch	15.6 (9.7 mi)	365	48,672

[a] d is the distance in kilometers from the airport to the RPF site (200 × distance squared).

RPF = radioisotope production facility.

Based on the results shown above and NUREG-0800, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*, COU needs to be further evaluated. The guidance also requires that special consideration be given to facilities sited within the trajectory of a runway of any airport. The RPF site is not located within a trajectory of a runway of the airport.

NUREG-0800, Section 3.5.1.6, provides a methodology for determining the probability of an aircraft crash into a facility from airports. The probability of an aircraft crashing into the RPF site is estimated using the following equation.

$$Pa = \sum_{i=1}^{L} \sum_{j=1}^{M} C_j N_{ij} A_j$$

Where:

- M = Number of different types of aircraft using the airport
- L = Number of flight trajectories affecting the airport
- C_j = Probability per square mile of a crash per aircraft movement for the $_{jth}$ aircraft
- N_{ij} = Number (per year) of operations by the $_{jth}$ aircraft along the $_{ith}$ flight path
- A_j = Effective area (in square miles) for the $_{jth}$ aircraft

The different aircraft using COU include those categorized as air carrier, air taxi, military, and general aviation. Military aircraft are further divided into large (bombers, cargo aircraft, and tankers) and small (fighters, attack aircraft, and trainers).

The effective area for each aircraft associated with the RPF was calculated in EDF-3124-0015, *Evaluation of Aircraft Hazards*. Because the probability per square mile of a crash per aircraft movement (C_j) is not available in NUREG-0800, for most aircraft at distances greater than 5 mi, the probability was calculated using DOE-STD-3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*.

This methodology uses the orthonormal distance from the RPF measured as the closest point to the center of each runway at COU [f(x,y)]. The aircraft crash probability is obtained from Tables B-2 through B-13 of DOE-STD-3014-2006. If the orthonormal distance is outside the boundaries of the tables, the f(x,y) is assumed to be zero. For military aircraft, the "pattern" side of the runways needs to be identified. For COU, the pattern side is left (AirNav, 2017). Table 2-15 provides the orthonormal coordinates for each runway.

Table 2-15. Orthonormal Coordinates for Columbia Regional Airport Runways to the Radioisotope Production Facility

Runway	Distance (mi)	Bearing to RFP	Runway bearing	x	y
20	6.69	333.17	133.17	2.27945	6.28969
2	6.69	329.23	309.23	-1.43955	6.53328
13	6.32	329.23	199.23	1.63167	6.10574
31	6.32	329.23	19.23	-5.86812	2.34682

RPF = radioisotope production facility.

Since the exact number of landings and takeoffs is not known for each aircraft, half of the operations are considered to be takeoff and half landings. This is conservative because total operations include activities such as an aircraft contacting the tower for a change of vector. In addition, the City of Columbia has an annual airshow on Memorial weekend, this activity is included in the Columbia Regional Airport annual flights per year.

COU has two runways: 13-31 and 2-20. It is assumed that 95 percent of all aircraft currently use runway 2-20 because runway 13-31 is a crosswind runway. In addition, large aircraft currently cannot use runway 13-31. COU is currently expanding and upgrading the airport, and by 2019, runway 13-31 will be usable for large aircraft. The number of operations per year was distributed between the two runways by this percentage. Probabilities of a crash for each aircraft was calculated for each bearing associated with each runway (130, 310, 200, and 20).

The probability crash rates for each type of aircraft category is obtained from DOE-STD-3014-2006, Table B-1. The impact frequency is then calculated by multiplying the f(x,y) value by the crash rate and affective area. Table 2-16 provides the results.

Table 2-16. Probability of Crashes from Airport Operations (2 pages)

Runway/Type of operations	Number of operations per year	x distance (mi)	y distance (mi)	f(x,y) value	P crash rate	A (mi²)	Impact frequency
20							
General aviation takeoff	7,025	-2.27945	6.289691	0	2.00E-04	0.00482234	0.00E+00
General aviation landing	7,025	-2.27945	6.289691	0	2.00E-04	0.00482234	0.00E+00
Commercial air carrier takeoff	503	-2.27945	6.289691	0	4.00E-07	0.018606226	0.00E+00
Commercial air carrier landing	503	-2.27945	6.289691	0	4.00E-07	0.018606226	0.00E+00
Air taxis takeoff	1,839	-2.27945	6.289691	0	1.00E-06	0.015346798	0.00E+00
Air Taxis landing	1,839	-2.27945	6.289691	0	1.00E-06	0.015346798	0.00E+00
Military large takeoff	760	-2.27945	6.289691	0	2.00E-07	0.020269746	0.00E+00
Military large landing	760	-2.27945	6.289691	2.90E-03	2.00E-07	0.020269746	8.93E-09

Table 2-16. Probability of Crashes from Airport Operations (2 pages)

Runway/Type of operations	Number of operations per year	x distance (mi)	y distance (mi)	f(x,y) value	P crash rate	A (mi²)	Impact frequency
2							
General aviation takeoff	7,025	-1.43956	6.533282	0	2.00E-04	0.00482234	0.00E+00
General aviation landing	7,025	-1.43956	6.533282	0	2.00E-04	0.00482234	0.00E+00
Commercial air carrier takeoff	503	-1.43956	6.533282	0	4.00E-07	0.018606226	0.00E+00
Commercial air carrier landing	503	-1.43956	6.533282	0	4.00E-07	0.018606226	0.00E+00
Air taxis takeoff	1,839	-1.43956	6.533282	0	1.00E-06	0.015346798	0.00E+00
Air Taxis landing	1,839	-1.43956	6.533282	0	1.00E-06	0.015346798	0.00E+00
Military large takeoff	760	-1.43956	6.533282	0	2.00E-07	0.020269746	0.00E+00
Military large landing	760	-1.43956	6.533282	2.30E-03	2.00E-07	0.020269746	7.08E-09
13							
General aviation takeoff	370	1.631671	-6.10574	0	2.00E-04	0.00482234	0.00E+00
General aviation landing	370	1.631671	-6.10574	0	2.00E-04	0.00482234	0.00E+00
Commercial air carrier takeoff	26	1.631671	-6.10574	1.10E-05	4.00E-07	0.018606226	2.17E-12
Commercial air carrier landing	26	1.631671	-6.10574	0	4.00E-07	0.018606226	0.00E+00
Air taxis takeoff	194	1.631671	-6.10574	1.10E-05	1.00E-06	0.015346798	3.27E-11
Air Taxis landing	97	1.631671	-6.10574	0	1.00E-06	0.015346798	0.00E+00
Military large takeoff	40	1.631671	-6.10574	0	2.00E-07	0.020269746	0.00E+00
Military large landing	40	1.631671	-6.10574	1.00E-05	2.00E-07	0.020269746	1.62E-12
31							
General aviation takeoff	370	-5.86812	2.346824	0	2.00E-04	0.00482234	0.00E+00
General aviation landing	370	-5.86812	2.346824	5.00E-04	2.00E-04	0.00482234	1.78E-07
Commercial air carrier takeoff	26	-5.86812	2.346824	0	4.00E-07	0.018606226	0.00E+00
Commercial air carrier landing	26	-5.86812	2.346824	7.10E-05	4.00E-07	0.018606226	1.40E-11
Air taxis takeoff	194	-5.86812	2.346824	0	1.00E-06	0.015346798	0.00E+00
Air Taxis landing	97	-5.86812	2.346824	7.10E-05	1.00E-06	0.015346798	1.05E-10
Military large takeoff	40	-5.86812	2.346824	0	2.00E-07	0.020269746	0.00E+00
Military large landing	40	-5.86812	2.346824	3.40E-03	2.00E-07	0.020269746	5.51E-10

The impact frequency for each aircraft category is as follows;

- General aviation 1.78E-07
- Commercial air carrier 1.61E-11
- Air taxis 3.27E-11
- Military large 1.66E-08

Because the three heliports are closer than 8 km (5 mi) to the RPF site, the frequency of an aircraft crashing into the site needs to be evaluated. NUREG-0800, Section 3.5.1.6, "Aircraft Hazards," provides a methodology for determining the probability of an aircraft crash into a facility from airways. However, the approach requires knowledge of the number of flights per year along the airway.

Because this information is not available for the flight paths near the RPF, DOE-STD-3014-2006 was used to determine the frequency of crashes. The following equation is used.

$$F_h = N_h \times P_h \times f_h(x,y) \times A_h$$

Where:

F_h	=	Crash impact frequency
N	=	Flight per year
P_h	=	Probability of a crash
$f_h(x,y)$	=	Probability, given a crash, that the crash occurs in a 2.6 km^2 (1-mi^2) area surrounding the facility
A_h	=	Effective plant area

The effective area for an aircraft was determined by two components: the aircraft crashing into the facility either by skidding or by flying directly into it. The effective area was calculated based on an aircraft skidding or flying into the facility in the direction that produces the largest area (i.e., crashing in a direction perpendicular to the largest diagonal of the building).

The following formula was used to calculating the skid and fly in areas of an aircraft crashing into the facility.

$$A_{eff} = A_f + A_s$$

Where:

$$A_f = (WS + R) \times H \times cot\phi + \frac{(2 \times L \times W \times WS)}{R} + L \times W$$

and:

$$A_s = (WS + R) \times S$$

Where:

A_f	=	Effective fly-in area
As	=	Effective skid area
WS	=	Aircraft wingspan
R	=	Length of the diagonal of the facility = $\sqrt{L^2 + W^2}$
H	=	Facility height, facility-specific
cotΦ	=	Mean of the cotangent of the aircraft impact angle
L	=	Length of facility, facility-specific
W	=	Width of facility, facility-specific
S	=	Aircraft skid distance (mean value).

DOE-STD-3014-2006 notes that in calculating an effective area, the analyst needs to be cognizant of the "critical areas" of the facility. The critical areas are locations in a facility that contain hazardous material and/or locations that, once impacted by a crash, can lead to cascading failures (e.g., a fire, collapse, and/or explosion that would impact the hazardous material). The critical areas of the RPF are considered to be the hot cell and waste management areas.

The critical areas dimensions are estimated at 30.5 × 24 m (100 × 80 ft), which provides a diagonal (R) of 39 m (128 ft). The facility height (H) of 22.9 m (75 ft) was used. DOE-STD-3014-2006 provides estimates for aircraft wingspan, mean of the cotangent of the aircraft impact angle, and skid distance for five different aircraft types. For helicopters, the cotΦ value is 0.58 and the skid length is typically assumed to be 0. The effective area is calculated in Table 2-19.

Table 2-17. Affective Area for Helicopter

Aircraft	Wing span[a] WS (ft)	cotΦ[a]	Skid distance[a] S (ft)	Effective plant area A_h (mi^2)
Helicopter	50	0.58	0	0.00079

[a] DOE-STD-3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, U.S. Department of Energy, Washington, D.C., 1996 (R2006).

For a helicopter, fh(x,y) is estimated based on half the average length of a flight with the lateral variations in crash locations assumed to be 0.4 km (0.25 mi) on the average from the centerline of the flight path, or 2/L. The probability Ph (2.50E-05) is taken from DOE-STD-3014-2006, Appendix B, Table B-1. The total number of flights from the three helipads is estimated at 1,825 per year. A conservation estimate is that 5 percent of these helicopters overfly the facility. In addition, a conservative estimate of total flight path is the distance to the closest helipad or 6 km (3.7 mi).

Based on these assumptions, the helicopter impact frequency is calculated as follows:

$$F_h = 91 \times 2.5E^{-05} \times \frac{2}{3.7} \times 7.9E^{-04}$$

$$F_h = 9.7E^{-07}$$

The calculated crash impact frequency from the heliport is less than the requirement of NUREG-0800 of being within an order of magnitude of 10^{-7} per year.

2.2.2.2 Airways

There are seven federal airways located within 16 km (10 mi) of the RPF site. NUREG-1537 calls for the evaluation of frequency and type of aircraft movement, flight patterns, local meteorology, and topography. NUREG-0800, Section 3.5.1.6, was used to evaluate airways near the RPF site. NUREG-0800 indicates that an evaluation is not required when the nearest edge of the airway is greater than 3.2 km (2 mi) from the facility. Four of the seven airways (J24, J181, V12, and V63) fall within 3.2 km (2 mi) of the proposed RPF site (Table 2-18).

Table 2-18. Federal Designated Airways within 16 km (10 mi) of the Radioisotope Production Facility Site

Airway	Distanced from airway centerline to RPF		Airway width		Distance from airway edge to RPF	
	km	mi	km	mi	km	mi
J24	17.3	10.75	Not specified	Not specified	Within	Within
J181	4.8	3	Not specified	Not specified	Within	Within
V12	6.8	4.25	14.8	9.2	Within	Within
V44	11.2	7	14.8	9.2	3.8	2.4
V63	0.40	0.25	14.8	9.2	Within	Within
V175	19.3	12	14.8	9.2	11.9	7.4
V178/V239	11.2	7	14.8	9.2	3.8	2.4

RPF = radioisotope production facility.

The hazards associated with these airways are evaluated in Section 2.2.2.5. Figure 2-30 identifies the centerline of federal airways within 10 mi (16 km) of the RPF site.

2.2.2.3 Military Airports and Training Routes

There are no military airports or training routes located within 16 km (10 mi) of the RPF site.

2.2.2.4 Approach and Holding Patterns

According to air traffic control at COU, the controllers do not typical hold any traffic. However, if traffic is held, the aircraft are typically within their designated airspace, 8 km (5 mi) (Figure 2-29). The hazards associated with these airways are evaluated in Section 2.2.2.5.

2.2.2.5 Evaluation of Aircraft Hazard

NUREG-0800, Section 3.5.1.6, provides a methodology for determining the probability of an aircraft crash into a facility from airways. However, the approach requires knowledge of the number of flights per year along the airway. Because this information is not available for the flight paths near the RPF, DOE-STD-3014-2006 was used.

This method uses crash rates for non-airport operations. The following formula from the DOE standard was used.

$$F_j = N_j \times P_j \times f_j(x,y) \times A_j$$

Where:

F_j	=	Crash impact frequency
j	=	Each type of aircraft suggested in DOE-STD-3014-2006
N_jP_j	=	Expected number of in-flight crashes per year
$f_j(x,y)$	=	Probability, given a crash, that the crash occurs in a 1-mi^2 area surrounding the facility
A_j	=	Effective plant area.

DOE-STD-3014-2006 provides estimated $N_jP_jf_j(x,y)$ values for general and commercial aviation, and the average continental U.S. (CONUS) values were used. The effective area, A_j, for each aircraft category is determined by two components; the aircraft crashing into the facility either by skidding or by flying directly into it. The effective area is calculated based on an aircraft skidding or flying into the facility in the direction that produces the largest area (i.e., crashing in a direction perpendicular to the largest diagonal of the building). The following formula was used to calculating the skid and fly-in areas of an aircraft crashing into the facility.

$$A_{eff} = A_f + A_s$$

Where:

$$A_f = (WS + R) \times H \times cot\phi + \frac{(2 \times L \times W \times WS)}{R} + L \times W$$

and:

$$A_s = (WS + R) \times S$$

Where:

A_f	=	Effective fly-in area
As	=	Effective skid area
WS	=	Aircraft wingspan
R	=	Length of the diagonal of the facility = $\sqrt{L^2 + W^2}$
H	=	Facility height, facility-specific
cotΦ	=	Mean of the cotangent of the aircraft impact angle

L = Length of facility, facility-specific
W = Width of facility, facility-specific
S = Aircraft skid distance (mean value).

DOE-STD-3014-2006 notes that in calculating an effective area, the analyst needs to be cognizant of the "critical areas" of the facility. The critical areas are locations in a facility that contain hazardous material and/or locations that, once impacted by a crash, can lead to cascading failures (e.g., a fire, collapse, and/or explosion that would impact the hazardous material). The critical areas of the RPF are considered to be the hot cell and waste management areas.

The RPF critical areas dimensions are estimated at 30.5 × 24 m (100 × 80 ft), which provides a diagonal (R) of 39 m (128 ft). The height (H) is 13.7 m (45 ft). DOE-STD-3014-2006 provides estimates for aircraft wingspan, mean of the cotangent of the aircraft impact angle, and skid distance for five different aircraft types. The most conservative values were used in cases where there were more than one available for the specific aircraft. These values, along with the calculated effective plant area, are summarized in Table 2-19.

Table 2-19. Effective Area Input Values and Calculated Effective Plant Area

Aircraft	Average CONUS values $N_jP_jf_j(x,y)$[a]	Wing span WS (ft)[a]	cotΦ[a]	Skid distance S (ft)	Effective plant area A_j (mi^2)	Non-airport crash frequency F_j
Air carrier	4E-7	98	10.2	1440	0.01861	7.4E-09
Air taxi	1E-6	59	10.2	1440	0.01535	1.5E-08
Large military	2E-7	223	9.7	[b]780	0.02027	4.1E-09
Small military	4E-6	78	10.4	[c]447	0.00971	3.9E-08
General aviation airplanes	2E-4	73	8.2	60	0.00482	9.6E-07

Source: EDF-3124-0015, *Evaluation of Aircraft Hazards*, Rev. 2, Portage, Inc., Idaho Falls, Idaho, 2017.

[a] DOE-STD-3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, U.S. Department of Energy, Washington, D.C., 2006.

[b] Takeoff

[c] Landing

CONUS = continental United States.

The crash impact probabilities from airways, airport operations, and helicopter overflights are summed together to determine the overall probability for small and large aircraft. The resulting probability is 1.88E-06 (Table 2-20).

Table 2-20. Crash Impact Probabilities

	Airport operations	Overflights	Total
General Aviation	1.78E-07	6.77E-07	8.55E-07
Commercial Air Carrier	1.61E-11	6.27E-09	6.29E-09
Air Taxis	3.27E-11	1.30E-08	1.30E-08
Military Large	1.66E-08	3.12E-09	1.97E-08
Military Small	0.00E+00	2.82E-08	2.82E-08
Helicopters	–	9.70E-07	9.70E-07
Total	–	–	1.89E-06

NUREG-1537 does not provide acceptance criteria to be used to evaluate the aircraft accident probability. However, NUREG-0800 does provide criteria for assessment of aircraft accidents. For aircraft accidents, NUREG-0800, Section 3.5.1.6, states that "Aircraft accidents that could lead to radiological consequences in excess of the exposure guidelines of 10 CFR 100 with a probability of occurrence greater than an order of magnitude of 10^{-7} per year should be considered in the design of the plant." The calculated crash impact probabilities from airways for all five aircraft types is slightly larger than an order of magnitude of 10^{-7} per year. Therefore, a general aviation crash will be evaluated as part of the integrated safety analysis (ISA) external event analysis and included in the Operating License Application.

2.2.3 Analysis of Potential Accidents at Facilities

On the basis of the information provided in Sections 2.2.1 and 2.2.2, the potential accidents to be considered as design-basis events and the potential effects of those accidents on the facility, in terms of design parameters (e.g., overpressure, missile energies) or physical phenomena (e.g., impact, flammable or toxic clouds), were identified in accordance with:

- 10 CFR 20, "Standards for Protection Against Radiation"
- 10 CFR 50.34, "Contents of Applications; Technical Information"
- Regulatory Guide 1.78, *Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release*
- Regulatory Guide 1.91, *Evaluations of Explosions Postulated to Occur at Nearby Facilities and on Transportation Routes Near Nuclear Power Plants*
- Regulatory Guide 1.206, *Combined License Applications for Nuclear Power Plants*
- Regulatory Guide 4.7, *General Site Suitability Criteria for Nuclear Power Stations*
- NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors - Format and Content.*
- NUREG-0800, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*
- *Handbook of Chemical Hazard Analysis Procedures* (FEMA, 1989)
- NUREG-1520, *Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility*
- NUREG-1805, *Fire Dynamics Tools (FDT^s) – Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program*
- NUREG/CR-6624, *Recommendations for Revision of Regulatory Guide 1.78*

The events are discussed in the following subsections.

2.2.3.1 Determination of Design-Basis Events

NUREG-1520, *Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility*, defines an external event as being not credible "if the event has a frequency of occurrence that can conservatively be estimated as less than once in a million years (10^{-6})." Design-basis events external to the NWMI RPF are defined as those accidents that have a probability of radiological release to the public 1×10^{-6} year, or greater, with the potential consequences serious enough to affect the safety of the plant to the extent that the guidelines in 10 CFR 50.34 could be exceeded.

The following accident categories were considered in selecting design-basis events: explosions, flammable vapor clouds (delayed ignition), toxic chemicals, and fires. The postulated accidents that would result in a chemical release were analyzed at the following locations:

- Nearby transportation routes such as U.S. Highway 63 and nearby natural gas pipelines
- Nearby chemical and fuel storage facilities.

2.2.3.1.1 Explosions

The impacts associated with accidents that involve high explosives, munitions, chemicals, and liquid or gaseous fuels stored or used by facilities near the proposed RPF were evaluated to analyze the structural response to blast pressures. This analysis included the evaluation of explosions from nearby railways, highways, or facilities and the resulting blast pressure on critical plant structures to ensure that such an explosion would not adversely affect operation or safe shutdown of the RPF.

The Regulatory Guide 1.91 and its recommended 6.9 kilopascal (kPa) (1 pound per square inch [lb/in^2]) value of peak positive incident overpressure was used to provide guidance in defining the allowable (i.e., standoff) and actual distances of hazardous chemicals transported or stored. Analyses that result in pressure below 6.9 kPa (1 lb/in^2) are not expected to result in significant damage. The guide defines this standoff distance by the correlation of R > kW1/3, where R is the distance in feet from an explosion comprised of W pounds of trinitrotoluene (TNT), and a constant value k. NUREG-1805 was used to define the TNT mass equivalent (W). This guide compares the heat of combustion of the chemical is to the heat of combustion of TNT.

In some cases, the result using the NUREG-1805 methods returned standoff distances greater than the actual distance of the analyzed incident to the RPF. In those cases, a probabilistic analysis was used to show that the rate of exposure to the overpressure in excess of 6.9 kPa (1 lb/in^2) is less than 1×10^6 per year using conservative assumptions.

The conservative assumptions included an explosion yield factor, the estimation of the available combustion energy released during an explosion, of 100 percent. This accounts for an in-vessel confined explosion and is considered to be conservative because a 100 percent yield factor is not achievable. Another conservative assumption used was that for liquids at atmospheric conditions, the storage tank was assumed to contain vapors at the upper explosive limit. Because the upper explosive limit produces the maximum explosive mass and liquid vapor explodes, not the liquid, this is considered conservative. These assumptions are consistent with NUREG-1805, Chapter 15.

The analysis performed does not bound an explosion of the total inventory of nearby facilities. The analysis uses the largest tank for two identified facilities to determine the effect on RPF operations or safe shutdown. It was determined to be highly unlikely for the total inventory from both facilities to be involved in the explosion scenario due to the following:

- MU South Farm (the closest facility) – The total inventory of propane is in multiple disperse locations
- Magellan Pipeline facility – An accidental explosion of multiple tanks at one time adding to the pressure wave is also highly unlikely.

For compressed or liquefied gases (i.e., propane, hydrogen), the entire contents of the storage vessel were assumed to be between the upper and lower explosive limits. An instantaneous depressurization of the vessel would result in vapor concentrations all within the explosive range at varying pressures and temperatures some of which would be below explosive limits. Therefore, assuming the entire contents are within the explosive limits is considered conservative.

For unconfined explosions of propane, methane, or hydrogen, the yield factor of 3 percent from the *Handbook of Chemical Hazard Analysis Procedures* (FEMA, 1989) was used.

Pipelines

A stationary pipeline explosion is bounded by the delayed ignition explosion of that pipeline due to the wind is assumed to blow the release towards the RPF with a constant mass release rate from the pipeline that results in a much larger total explosive mass. Thus, the distance from the point of the explosion to the NWMI RPF is therefore much smaller for flammable vapor clouds than for pipeline explosions at the release point.

Waterway Traffic

There are no navigable waterways within 8 km (5 mi) of the RPF.

Highways

Hazardous materials with explosive potential that may possibly be transported on U.S. Highway 63 is shown in Table 2-21 (EDF-3124-0016, *Analysis of Potential Accidents at Facilities*) include [Proprietary Information]. The remaining chemicals identified in Table 2-21 are nonexplosive. The maximum quantity of the identified chemicals assumed to be transported on the highway was 22,679 kg (50,000 lb) per Regulatory Guide 1.91. The volume of hydrogen was assumed to be 1,496 kg (3,300 lb) on a single truck per 49 CFR 173.318, "Cryogenic Liquids in Cargo Tanks."

Table 2-21 provides the results of the analysis using the TNT equivalency methodologies described in within this section. For all chemicals analyzed, the minimum separation distances (i.e., safe standoff distances) are less than the shortest distance (0.4 km [0.25 mi]) to a safety-related RPF structure from any point on U.S. Highway 63. The peak incident pressure is 6.9 kPa (1 lb/in.^{2}) at a distance greater than the shortest distance from U.S. Highway 63 to a safety-related RPF structure of 0.4 km (0.25 mi).

Table 2-21. Distance from the Radioisotope Production Facility where the Peak Incident Pressure is 6.9 kPa (1 lb/in.^{2}) from an Explosion on U.S. Highway 63

Hazardous material	Quantity		Acceptable distance peak incident pressure is 6.9 kPa (1 lb/in.^{2})	
	kg	lb	km	mi
Ammonia	22,680	50,000	0.27	0.17
Diesel	22,680	50,000	0.1	0.06
Gasoline	22,680	50,000	0.1	0.06
Glycol ether PM	22,680	50,000	0.1	0.06
Hydrogen	1,497	3,300	0.21	0.13
JP-4 aviation fuel	22,680	50,000	0.1	0.06
Methyl ethyl ketone	22,680	50,000	0.1	0.06
Petroleum naphtha	22,680	50,000	0.1	0.06
Propane	22,680	50,000	0.34	0.21
Toluene (32-8413)	22,680	50,000	0.1	0.06

Source: EDF-3124-0016, *Analysis of Potential Accidents at Facilities*, Rev. 2, Portage, Inc., Idaho Falls, Idaho, 2017.

A boiling liquid expanding vapor explosion (BLEVE) is an explosion caused by the rupture of a vessel containing a pressurized liquid above its boiling point (Roberts, 2000). A BLEVE overpressure for the propane tank was analyzed in detail. The 22,680 kg (50,000 lb) propane tank, i.e., 45,425 liter (L) (12-thousand gallon [kgal]), was assumed to fail at 55 degrees Celsius (°C) (320 lb/in.^{2} absolute). The entire contents of the tank (e.g., gas and liquid) were assumed to be involved in the BLEVE. The acceptable distance to 6.9 kPa (1 lb/in.^{2}) overpressure is 0.21 km (0.13 mi). The shortest distance to a safety-related RPF structure from any point on U.S. Highway 63 is 0.4 km (0.25 mi).

A BLEVE overpressure for the hydrogen tank was also analyzed in detail. The 1,497 kg (3,300 lb) propane tank (i.e., 45,425 L [12 kgal]) was assumed to fail at -240°C (183 lb/in.^{2} absolute), the point before the hydrogen becomes supercritical. The entire contents of the tank (e.g., gas and liquid) were assumed to be involved in the BLEVE. The acceptable distance to 6.9 kPa (1 lb/in.^{2}) overpressure is 0.08 km (0.05 mi). The shortest distance to a safety-related RPF structure from any point on U.S. Highway 63 is 0.4 km (0.25 mi).

Based on the above, an explosion involving potentially transported hazardous materials on U.S. Highway 63, would not adversely affect operation of the RPF. The results of the highway explosion analyses are provided in Table 2-21 (EDF-3124-0016).

2.2.3.1.2 Nearby Facilities

Analysis identified six off-site facilities that have explosive chemicals that are identified as the bounding instances of explosion analysis. The hazardous materials stored at nearby facilities that were identified for further analysis with regard to explosive potential are identified in Table 2-22.

Table 2-22. Analysis of Hazardous Chemicals Stored Within 8 km (5 mi) of the Radioisotope Production Facility (2 pages)

Company	Hazardous material	Distance		Mass		Acceptable distance (1 lb/in.^{2})	
		km	mi	kg	lb	km	mi
3M Company	[Proprietary Information]	>8	>5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Schwan's Home Service Inc.	[Proprietary Information]	3.2	2	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Gates Power Transmissions Materials Center	[Proprietary Information]	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Gates Power Transmissions Materials Center	[Proprietary Information]	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
MU South Farm	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
MU South Farm	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
MU South Farm	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Ryder Transportation	[Proprietary Information]	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Magellan Pipeline Company	[Proprietary Information]	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

Table 2-22. Analysis of Hazardous Chemicals Stored Within 8 km (5 mi) of the Radioisotope Production Facility (2 pages)

Company	Hazardous material	Distance		Mass		Acceptable distance (1 lb/in.^{2})	
		km	mi	kg	lb	km	mi
Magellan Pipeline Company	[Proprietary Information]	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

Source: EDF-3124-0016, *Analysis of Potential Accidents at Facilities*, Rev. 2, Portage, Inc., Idaho Falls, Idaho, 2017.

[a] Actual tank mass provided by owner was used.

[b] [Proprietary Information]

[c] [Proprietary Information]

[d] [Proprietary Information]

[e] [Proprietary Information]

MU = University of Missouri

A conservative analysis using TNT equivalency methods, as described in Section 2.2.3.1, was used to determine standoff distances for the storage of the identified hazardous materials. Table 2-22 provides the results of the analysis (EDF-3124-0016). The analysis showed that a [Proprietary Information]. The nearest tank of propane is approximately [Proprietary Information]. However, the propane at this location is stored in multiple tanks, the largest of which is [Proprietary Information].

The results using this methodology indicate that the minimum separation distances (i.e., safe standoff distances) are less than the shortest distance from an RPF safety-related area to the storage location of the identified chemicals. Therefore, an explosion of any of these chemicals would not adversely affect operation of the RPF.

Railways

The only railroad within the 8 km (5 mi) radius of the RPF is the COLT Transload, which provides service for the Columbia Municipal Power Plant and a commercial lumber facility to the north of downtown Columbia. This rail line dead-ends approximately 7.2 km (4.5 mi) from the RPF. A review of the Tier II facilities did not identify any facilities with potentially hazardous chemicals near the rail line within 8 km (5 mi) radius of the RPF.

Explosion-Related Impacts Affecting Design

Regulatory Guide 1.91 cites 6.9 kPa (1 lb/in.^{2}) is considered a conservative value of peak positive incident overpressure, below which no significant damage would be expected. Thus, facility is acceptable when the calculated rate of occurrence of severe consequences from any external accident is less than 1×10^{-6} occurrences per year, and reasonable qualitative arguments can demonstrate that the realistic probability is lower. The RPF safety-related areas are designed to withstand a peak positive overpressure of at least 6.9 kPa (1 lb/in.^{2}) without loss of function/significant damage, as shown in Table 2-21 and Table 2-22. As a result, postulated explosion event scenarios will not result in severe consequences.

On-Site Diesel Fuel Tank

The RPF will have a 3,785 L (1-kgal) tank of diesel fuel within 9.1 m (30 ft) of the building. A tank containing 3,785 L (1 kgal) of diesel fuel is acceptable at a distance of 49.1 m (161 ft). Therefore, the on-site diesel explosion is analyzed using a probabilistic analysis. The total probability of a significant explosion is estimated using the probability of a spill and the conditional probability of an explosion given a spill.

The probability of a large release from a single-walled stationary tank at a fixed facility is 1×10^{-5} spills per year, and the probability of a spill from a double-walled stationary tank is 1×10^{-6} spills per year (FEMA, 1989). The rate of explosions per spill from diesel tanks is very low. A report on ignition probabilities for oil and gas (OGP, 2010) states that for releases of "combustible liquids stored at ambient pressure and at temperatures below their flash point from onshore outdoor storage area" tanks, the ignition probability is at most 0.24 percent. Combined with the single-walled tank spill probability, the frequency of an ignition is 2.4×10^{-8} ignitions per year, significantly less than the acceptance criteria.

2.2.3.1.3 Flammable Vapor Clouds (Delayed Ignition)

When a flammable chemical (e.g., liquid or gaseous state) is released into the atmosphere and forms a vapor cloud, the chemical disperses as it travels downwind. The portions of the vapor cloud where the concentration is within the flammable range, between the lower and upper flammability limits, may burn if the cloud encounters an ignition source. Deflagration or a detonation of the vapor cloud is determined by the pace of the flame through the vapor cloud. If the cloud burns fast enough to create a detonation, an explosive force is generated.

Chemicals were evaluated to ascertain which hazardous materials had the potential to form a flammable vapor cloud or vapor cloud explosion. The chemicals identified within flammability range, the Areal Locations of Hazardous Atmospheres (ALOHA) air dispersion computer model was used (ALOHA, 2008).

ALOHA was used to:

- Determine the distances where the vapor cloud may exist between the upper explosion limit and the lower explosion limit (LEL), presenting the possibility of ignition and potential thermal radiation effects.
- Model the worst-case accidental vapor cloud explosion, including the standoff distances and overpressure effects at the nearest RPF safety-related area. The worst-case scenario was assumed to be ignition by detonation was chosen for the ignition source with the standoff distance measured as the distance from the spill site to the location where the pressure wave is at 6.9 kPa (1 lb/in.^{2}) overpressure.

Conservative assumptions were used in both ALOHA analyses with regard to meteorological inputs and identified scenarios. The following meteorological assumptions were used as inputs to the ALOHA model:

- Pasquill Stability Class F (stable), with a wind speed of 1 meter per second (m/sec) (3.3 ft/sec)
- Ambient temperature of 27°C (81 degrees Fahrenheit [°F])
- Relative humidity 50 percent
- Cloud cover 50 percent
- Atmospheric pressure of 1 atmosphere.

Pasquill Stability Class F was selected based on local weather data. Class F represents the 5 percent worst-case weather conditions at the RPF site. For each of the identified liquid chemicals, the entire contents of the vessel were conservatively assumed to have leaked, forming a 1 centimeter (cm) (0.4-inch [in.]) thick puddle. For gaseous chemicals, the entire contents were released instantaneously as a gas. This provides a significant surface area to maximize evaporation and the formation of a vapor cloud in the case of liquid releases, and maximizes the peak concentration in the case of gas releases.

Pipelines

There are three natural gas transmission pipelines within 8 km (5 mi) of the proposed RPF. These pipelines include the Southern Star Central Gas Pipeline, Inc. located 1.6 km (1 mi), Ameren natural gas transmission pipeline #1 located approximately 0.64 km (0.40 mi), and Ameren natural gas transmission pipeline #2 located approximately 6.0 km (3.75 mi) from the RPF site.

Transmission pipelines are made of steel and generally operate at pressures ranging from 344 kPa (500 lb/in.^{2}) to 9,652 kPa (1,400 lb/in.^{2}) gauge. Pipelines can measure anywhere from 15.25 cm (6 in.) to 122 cm (48 in.) in diameter (ANL/EVS/TM/08-5, *Natural Gas Pipeline Technology Overview*).

Each natural gas pipeline was modeled as a complete break, with a constant source of natural gas available to break. An analysis was performed using the ALOHA model. A summary of the results is provided below, and the calculations are provided in EDF-3124-0016):

- Southern Star Natural Gas Transmission Pipeline:
  - [Proprietary Information]
  - Highest typical transmission pipeline pressure of 9,652 kPa (1400 lb/in.^{2}) was assumed
  - Distance to the LEL is [Proprietary Information], which is less than the distance of [Proprietary Information] to the RPF
  - Results: Due to the concentration of natural gas being below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility, and therefore, there will be no explosive overpressure.
- Ameren Natural Gas Transmission Pipeline #1:
  - [Proprietary Information]
  - Highest typical transmission pipeline pressure of 2,000 kPa (290 lb/in.^{2}) was assumed
  - Distance to the LEL is [Proprietary Information], which is much less than the [Proprietary Information] distance to the RPF
  - Results: Due to the concentration of natural gas being below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility; therefore, there will be no resulting explosive overpressure.
- Ameren Natural Gas Transmission Pipeline #2:
  - [Proprietary Information]
  - Highest typical transmission pipeline pressure of 9,652 kPa (1,400 lb/in.^{2})
  - Distance to the LEL from the Ameren natural gas pipeline is [Proprietary Information], which is less than the distance of [Proprietary Information] to the RPF site
  - Results: Due to the concentration of natural gas being below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility, and therefore, there will be no explosive overpressure.

Waterway Traffic

There are no navigable waterways within 8 km (5 mi) of the RPF.

Highways

The hazardous materials potentially transported on U.S. Highway 63 that were identified for further analysis are diesel, gasoline, JP-4, petroleum naphtha, toluene, glycol ether PM, methyl ethyl ketone, hydrogen, propane, and ammonia. The remaining chemicals are nonexplosive. The closest RPF safety-related area is located approximately 0.40 km (0.25 mi) from U.S. Highway 63.

Consistent with Regulatory Guide 1.91, the tanker trucks are conservatively estimated, at most, to carry and release 22,680 kg (50,000 lb) of the identified chemical. The analyzed effects of flammable vapor clouds and vapor cloud explosions from external sources are summarized in Table 2-23 (EDF-3124-0016).

Table 2-23. Flammable Vapor Cloud Explosion Analysis for U.S. Highway 63

Hazardous material	Quantity		Acceptable distance (LEL)		Probability[a]
	kg	lb	km	mi	
Ammonia	22,680	50,000	0.93	0.58	2.2×10^{-7}
Diesel	22,680	50,000	0.35	0.22	-
Gasoline	22,680	50,000	0.35	0.22	-
Glycol ether PM	22,680	50,000	0.06	0.04	-
Hydrogen	1,497	3,300	1.24	0.77	3.0×10^{-7}
JP-4 aviation fuel	22,680	50,000	0.35	0.22	-
Methyl ethyl ketone	22,680	50,000	0.19	0.12	-
Petroleum naphtha	22,680	50,000	0.35	0.22	-
Propane	22,680	50,000	1.37	0.85	$>1 \times 10^{-6}$
Toluene (32-8413)	22,680	50,000	0.13	0.08	-

Source: EDF-3124-0016, *Analysis of Potential Accidents at Facilities*, Rev. 2, Portage, Inc., Idaho Falls, Idaho, 2017.

[a] Probability only calculated for chemicals with acceptable distances greater than 0.4 km (0.25 mi).

LEL = lower explosion limit.

To determine the probability of an accident affecting the RPF, the number of transports per year needs to be known. The number of trucks hauling hazardous materials on U.S. Highway 63 is not available. To determine the probability that an explosion could affect the RPF, estimates of truck shipments were made based on the major uses of these materials within 8 km (5 mi) of the RPF.

All releases of an accident affecting the RPF (i.e., hydrogen, chlorine, ammonia) from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis and are provided below. The assumptions used in all analysis include:

- Accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill
- When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release
- Accident data were taken from NUREG/CR-6624, *Recommendations for Revision of Regulatory Guide 1.78*, and FEMA (1989).

Hydrogen

The largest amount of hydrogen on a truck that was analyzed was 1,496 kg (3,300 lb). The accident analysis showed that a 30 percent release of hydrogen resulted in a distance to the LEL of 0.79 km (0.49 mi). In addition, the analysis showed that a 10 percent release of hydrogen resulted in a distance to the LEL of 0.53 km (0.33 mi) (EDF-3124-0016). The probability of an explosion from a hydrogen truck accident is 1.6×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill × 0.2 ignition probability). The accident probability within 1.24 km (0.77 mi) of the RPF (i.e., 0.96 km [1.54 mi] total for U.S. Highway 63) would be 2.5×10^{-8} per truck release scenario to meet the LEL.

The Colombia Municipal Power Plant is the major user of hydrogen with 1,497 kg (3,300 lb) being stored within 8 km (5 mi) radius of the RPF. This hydrogen is assumed to be used for generator cooling. The annual usage is not available; however, an assumption is made that hydrogen makeup requires the tank to be refilled monthly. This would result in 12 shipments of hydrogen potentially passing the RPF annually, and change the probability to 3.0×10^{-7} per year. No additional analysis are required for hydrogen.

Propane

The accident analysis showed that a 30 percent release of propane resulted in a distance to the LEL of 0.87 km (0.54 mi). In addition, the analysis showed that a 10 percent release of propane resulted in a distance to the LEL of 0.58 km (0.36 mi). The probability of an explosion from a propane truck accident is 1.6×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill × 0.2 ignition probability). The accident probability within 1.4 km (0.85 mi) of the RPF (e.g., 2.7 km [1.7 mi] total for U.S. Highway 63) would be 2.7×10^{-8} per truck release scenario to meet the LEL

There are three propane distributers in the Columbia, Missouri area: MFA Oil Company, Ballenger's Propane Inc., and Ferrellgas. The MFA Oil Company is located north of the RPF on U.S. Highway 63, while Ballenger's Propane Company and Ferrellgas are located north of Interstate 70. The distribution centers can receive their propane via rail and tanker trucks from terminals located in Kearney or Moberly, Missouri, along the Mid-American Pipeline, or Jefferson City along the Gold Line pipeline.

The majority of bulk propane transported to these facilities is assumed to be transported via Interstate 70 and does not bypass the RPF. However, propane could also be transported via U.S. Highway 63 from the terminal in Jefferson City to supply the distribution centers north of the RPF. The exact number of trucks transporting propane past the RFP is not known and could result in a probability exceeding 10^{-6}; therefore, this event will be evaluated as part of the ISA external event analysis and included in the Operating License Application.

Ammonia

The accident analysis showed that a 30 percent release of ammonia resulted in a distance to the LEL of 0.6 km (0.37 mi). In addition, the analysis showed that a 10 percent release of ammonia resulted in a distance to the LEL of 0.4 km (0.25 mi). The probability of an explosion from a propane truck accident is 1.6×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill × 0.2 ignition probability). The accident probability within 0.93 km (0.58 mi) of the RPF (e.g., 1.9 km [1.2 mi] total for U.S. Highway 63) would be 1.9×10^{-8} per truck release scenario to meet the LEL.

Kraft Foods stores 22,680 kg (50,000 lb) of ammonia, which is assumed to be used for refrigeration and potentially for heat pumps. In both cases, the losses and required makeup is expected to be small. A very conservative estimate of makeup would be to replace the entire 22,680 kg (50,000 lb) of ammonia monthly, or 12 shipments passing the RPF annually, and change the probability to 2.2×10^{-7} per year. No additional analysis are required for ammonia.

Nearby Facilities

There are eight off-site facilities that have explosive chemicals identified as the bounding instances of explosion analysis. The hazardous materials stored at nearby facilities that were identified for further analysis with regard to explosive potential are identified in Table 2-24. The methodology presented previously in this section was used for determining the standoff distance for vapor cloud ignition and delayed vapor cloud explosion. A conservative analysis using TNT equivalency methods, as described earlier in this section, was used to determine standoff distances for the storage of the identified hazardous materials.

Table 2-24. Flammable Vapor Clouds and Vapor Cloud Explosions from External Sources (2 pages)

Company	Hazardous material	Distance		Mass		Acceptable distance (LEL)	
		km	mi	kg	lb	km	mi
Plasma Motor Fuels LLC	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
3M Company	[Proprietary Information]	>8	>5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Schwan's Home Service Inc.	[Proprietary Information]	3.2	2	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Gates Power Transmissions Materials Center	[Proprietary Information]	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Gates Power Transmissions Materials Center	[Proprietary Information]	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
MU South Farm	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
MU South Farm	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
MU South Farm	[Proprietary Information]	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Ryder Transportation	[Proprietary Information]	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
Magellan Pipeline Company	[Proprietary Information]	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

Table 2-24. Flammable Vapor Clouds and Vapor Cloud Explosions from External Sources (2 pages)

Company	Hazardous material	Distance		Mass		Acceptable distance (LEL)	
		km	mi	kg	lb	km	mi
Magellan Pipeline Company	[Proprietary Information]	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

Source: EDF-3124-0016, *Analysis of Potential Accidents at Facilities*, Rev. 2, Portage, Inc., Idaho Falls, Idaho, 2017.

[a] Actual tank mass used.

[b] The maximum area of a spill in ALOHA is 31,400 square meters (m^2) – the inventory exceeds this value from a spill – therefore, 31,400 m^2 was used.

[c] [Proprietary Information]

[d] [Proprietary Information]

[e] [Proprietary Information]

ALOHA = Areal Locations of Hazardous Atmospheres.
LEL = lower explosion limit.
MU = University of Missouri.

The distance to the LEL for the propane tank containing [Proprietary Information] of propane corresponds to more than [Proprietary Information]. The nearest tank of propane is approximately [Proprietary Information] from the RPF. However, the propane at this location is stored in multiple tanks, the largest of which is [Proprietary Information]. The maximum content of a propane tank to meet the LEL at [Proprietary Information]. Flammable vapor clouds and vapor cloud explosions from external sources are summarized in Table 2-24 (EDF-3124-0016).

Flammable Vapor Cloud (Delayed Ignition) Related Impacts Affecting the Design

Regulatory Guide 1.91 cites 6.9 kPa (1 lb/in.^{2}) is considered a conservative value of peak positive incident overpressure, below which no significant damage would be expected. Thus, facility is acceptable when the calculated rate of occurrence of severe consequences from any external accident is less than 1×10^{-6} occurrences per year, and reasonable qualitative arguments can demonstrate that the realistic probability is lower. The RPF safety-related areas are designed to withstand a peak positive overpressure of at least 6.9 kPa (1 lb/in.^{2}) without loss of function/significant damage, as shown in Table 2-21 and Table 2-22. As a result, postulated explosion event scenarios will not result in severe consequences.

2.2.3.1.4 Toxic Chemicals Impacts Affecting Design

Accidents involving the release of toxic chemicals from nearby mobile and stationary sources were considered. Toxic chemicals known to be present in the vicinity of the proposed RPF site or to be frequently transported in the vicinity were evaluated.

The potential hazardous materials transported on U.S. Highway 63 were evaluated to ascertain which hazardous materials should be analyzed with respect to their potential to form a toxic vapor cloud following an accidental release. The ALOHA air dispersion model was used to predict the concentrations of toxic chemical clouds as they disperse downwind for all facilities and sources.

The maximum distance a cloud can travel before it disperses enough to fall below the immediately dangerous to life and health (IDLH) concentration in the vapor cloud was determined using ALOHA. The ALOHA model was also used to predict the concentration of the chemical in the control room following a chemical release to ensure that, under worst-case scenarios, control room operators will have sufficient time to take appropriate action.

The IDLH is defined by the National Institute of Occupational Safety and Health as a situation that poses a threat of exposure that is likely to cause death or immediate or delayed permanent adverse health effects, or one that could prevent escape from such an environment. The IDLHs determined by the National Institute of Occupational Safety and Health are established such that workers are able to escape such environments without suffering permanent health damage.

Conservative meteorological assumptions were used: F (stable) stability class with a wind speed of 1 m/sec, ambient temperature of 25°C, relative humidity of 50 percent, cloud cover of 50 percent, and atmospheric pressure of one atmosphere. A Pasquill stability category "F" and a wind speed of 1 m/sec typically represent the worst 5 percent of meteorological conditions observed at a majority of nuclear plant sites. For each of the identified chemicals, the entire contents of the vessel are conservatively assumed to have leaked, forming a one-centimeter-thick puddle.

Review of the chemicals at nearby facilities did not contain any toxic materials that would be greater than those located on U.S. Highway 63; therefore, only toxic chemicals on U.S. Highway 63 were considered in the analysis. The toxic chemicals considered in the analysis were ammonia, chlorine, and sulfur dioxide.

- The distance to the IDHL for an ammonia release from a truck on U.S. Highway 63 is 9.7 km (6 mi). This is greater than the distance from U.S. Highway 63 to the RPF of 0.40 km (0.25 mi).
- The distance to the IDHL for a chlorine release from a truck on U.S. Highway 63 is 1.8 km (1.1 mi). This is greater than the distance from U.S. Highway 63 to the RPF of 0.40 km (0.25 mi).
- The distance to the IDHL for a sulfur dioxide release from a truck on U.S. Highway 63 is 3.1 km (1.9 mi). This is greater than the distance from U.S. Highway 63 to the RPF of 0.40 km (0.25 mi).

All releases (i.e., ammonia, chlorine, sulfur dioxide) from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. The analysis for these release are provided below. The assumptions used in all analysis include:

- Accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill
- When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release
- Accident data were taken from NUREG/CR-6624 and FEMA (1989).

Ammonia

The accident analysis showed that a 30 percent release of ammonia resulted in a distance to the IDHL of 5.3 km (3.3 mi). In addition, the analysis showed that a 10 percent release of ammonia resulted in a distance to the IDHL of 3.1 km (1.9 mi). The probability of a spill from an ammonia truck accident is 8×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill). The accident probability within 9.7 km (6 mi) of the NWMI RPF (i.e., 19 km [12 mi] total for U.S. Highway 63) would be 9.6×10^{-7} per truck release scenario to meet the IDLH (EDF-3124-0016). The annual probability (i.e., when multiplied by 12 ammonia trucks annually) is greater than 1×10^{-6} per year; therefore, this event will be evaluated as part of the ISA external event analysis and included in the Operating License Application.

Chlorine

The accident analysis showed that a 30 percent release of chlorine resulted in a distance to the IDHL of 1.2 km (0.73 mi). In addition, the accident analysis showed that a 10 percent release of chlorine resulted in a distance to the IDHL of 0.8 km (0.52 mi). The probability of a spill from a chlorine truck accident is 8×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill). The accident probability within 1.8 km (1.1 mi) of the RPF (i.e., 3.6 km [2.2 mi] total for U.S. Highway 63) would be 1.76×10^{-7} per truck release scenario to meet the IDLH (EDF-3124-0016). The annual probability (i.e., when multiplied by only six trucks annually) is greater than 1×10^{-6} per year; therefore, this event will be evaluated as part of the ISA external event analysis and included in the Operating License Application.

Sulfur Dioxide

The accident analysis showed that a 30 percent release of sulfur dioxide resulted in a distance to the IDHL of 1.8 km (1.1 mi). In addition, the analysis showed that a 10 percent release of sulfur dioxide resulted in a distance to the IDHL of 1.1 km (0.66 mi). The probability of a spill from a chlorine truck accident is 8×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill). The accident probability within 3.1 km (1.9 mi) of the RPF (i.e., 6.2 km [3.8 mi] total for U.S. Highway 63) would be 3.0×10^{-7} per truck release scenario to meet the IDLH. The annual probability (i.e., when multiplied by only four trucks annually) is greater than 1×10^{-6} per year; therefore, this event will be evaluated as part of the ISA external event analysis and included in the Operating License Application.

2.2.3.1.5 Fires

Fires in adjacent industrial plants and storage facilities, oil and gas pipelines, and fires from transportation accidents were evaluated as events that could lead to high-heat fluxes. Three types of fires are analyzed for high-heat flux:

- BLEVE fireballs – Occurs when a tank containing a flammable liquefied gas bursts (e.g., similar to a BLEVE overpressure, the liquefied gas flashes which has a short duration)
- Pool fires – Occurs when a chemical that is liquid at standard conditions spills and catches fire
- Jet fires – Occurs when a pipeline ruptures or pressurized tank has a hole causing the continuous release of flammable gas

The limiting BLEVE fireball for the RPF is the rupture of a propane truck that contains 22,679 kg (50,000 lb) of liquefied propane and is 0.4 km (0.25 mi) from the RPF. ALOHA was used to calculate the heat flux and duration of the fireball. The results show that the heat flux on the RPF is 8.36 kilowatt (kW)/m^2 (2,650 British thermal units [BTU]/hr·square foot [ft^2]) and the duration of the fireball is 11 sec.

The American Concrete Institute has specified standards for short-term maximum bulk concrete temperatures of 177°C (350°F) following accidents (ACI 349-06, *Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-06) and Commentary*). NUREG/CR-3330, *Vulnerability of Nuclear Power Plant Structures to Large External Fires*, provides incident heat flux (kW/m^2) values and exposure times (hr) necessary for concrete to reach a temperature of 177°C (350°F). A heat flux of 15 kW/m^2 requires 11.6 hr of exposure for concrete to reach a temperature of 177°C (350°F), while a heat flux of 450 kW/m^2 requires 1.5 hr of exposure. Therefore, the heat flux from the propane BLEVE fireball will not impact the integrity of the RPF concrete structures (EDF-3124-0016).

The limiting pool fire would come from a gasoline truck on U.S. Highway 63. The truck contains 22,680 kg (50,000 lb) of gasoline and is 0.4 km (0.25 mi) from the RPF. The ALOHA model was used to calculate the heat flux for the pool fire. The results show that the maximum heat flux is 1.36 kW/m^2 (431.1 BTU/hr·ft^2) and the duration of the fireball is 60 sec. ACI 349-06 has specified standards for short-term maximum bulk concrete temperatures of 177°C (350°F) following accidents. Based on the NUREG/CR-3330 incident heat flux (kW/m^2) values and exposure times (hr) necessary for concrete to reach a temperature of 177°C (350°F) discussed above, the heat flux from the gasoline pool fire will not impact the integrity of the RPF concrete structures.

The Magellan pipelines were assumed to contain [Proprietary Information]. A conservative analysis was performed using the ALOHA model. The pipelines were assumed to be breached and spill the liquid contents in the soil, resulting in a liquid puddle that is [Proprietary Information].

The duration of the evaporating release was 1 hr. The total release of [Proprietary Information]. Based on the guidance used by the state of California (URS, 2007), which is a liquid flow rate of 2.13 m/sec (7 ft/sec) and the known pipeline diameter of [Proprietary Information]. URS (2007) also provides guidance for the time of release, which is 15 min. The liquid flow rate, along with the 15-min release duration, would result in a total release of [Proprietary Information]. Therefore, a conservative release of [Proprietary Information] was modeled in ALOHA based on the size of the release pool.

The distance to the LEL from the Magellan pipeline is 0.52 km (0.32 mi), which is less than the distance of 2.0 km (1.25 mi) to the proposed RPF site. Because the concentration of gasoline is below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility and there will be no explosive overpressure.

The three natural gas transmission pipelines within 8 km (5 mi) of the RPF are identified in Table 2-12. Transmission pipelines are made of steel and generally operate at pressures ranging from 344 kPa (500 lb/in.^{2}) to 9,652 kPa (1,400 lb/in.^{2}) gauge. Pipelines can measure anywhere from 15.25 cm (6 in.) to 122 cm (48 in.) in diameter (ANL/EVS/TM/08-5). A summary of the jet fire analysis that was performed using the ALOHA model (EDF-3124-0016) is provided below. The pipeline was modeled as a complete break, with a constant source of natural gas available to the break.

- Southern Star Natural Gas Transmission Pipeline:
  - [Proprietary Information]
  - Highest typical transmission pipeline pressure of 9,652 kPa (1400 lb/in.^{2}) was assumed
  - Distance to the LEL is [Proprietary Information], which is less than the distance of [Proprietary Information] to the RPF
  - Results: (1) Maximum heat flux is [Proprietary Information]; heat flux is negligible compared with the solar heat flux of approximately 1 kW/m^2 (0.088 BTU/ft^2), and (2) pipeline jet fire is not considered a threat to the RPF.
- Ameren Natural Gas Transmission Pipeline #1:
  - Pipeline diameter is [Proprietary Information]
  - Highest typical transmission pipeline pressure of 2,000 kPa (290 lb/in.^{2}) was assumed
  - Distance to LEL is at [Proprietary Information], which is much less than the [Proprietary Information] distance to the RPF
  - Results: (1) Maximum heat flux is [Proprietary Information] at the RPF; heat flux is negligible compared with the solar heat flux of approximately 1 kW/m^2 (0.088 BTU/ft^2), and (2) pipeline jet fire is not considered a threat to the RPF.

- Ameren Natural Gas Transmission Pipeline #2:
  - Pipeline diameter is [Proprietary Information]
  - Highest typical transmission pipeline pressure of 9,652 kPa (1,400 lb/in.^{2})
  - Distance to the LEL from the Ameren natural gas pipeline is [Proprietary Information], which is less than the distance of [Proprietary Information] to the RPF site
  - Results: (1) Maximum heat flux is [Proprietary Information]; heat flux is negligible compared with the solar heat flux of approximately 1 kW/m^2 (0.088 BTU/ft^2), and (2) pipeline jet fire is not considered a threat to the RPF.

2.3 METEOROLOGY

2.3.1 General and Local Climate

The purpose of this climate analysis is to provide the information that supports the dispersion analysis of airborne releases from the proposed RPF site. Local dispersion climatology includes consideration of airflow and atmospheric turbulence. The following subsections address local topography, the source of local meteorological data, wind roses, and atmospheric stability distribution.

The proposed RPF site is located in central Missouri. The purpose of conducting a climate analysis is to understand the climate (a statistical description of weather) at the local project site within the context of the climate of the broader surrounding area.

Geomorphic, or physiographic, regions are broad-scale subdivisions of the nation that are based on terrain texture, rock type, geologic structure, and history. There are eight regions, subdivided into 25 provinces, and further subdivided to 85 sections within the U.S. (Fenneman, 1946). The characteristics and locations of these landforms influence local and regional climate and weather patterns.

The RPF site lies at the southern edge of the Central Lowlands physiographic province, within a few miles of the adjacent Ozark Plateau province, both of which lie within the larger Interior Plains physiographic region. The Central Lowlands includes most of the Corn Belt and lies within the heartland of America.

The RPF location places it in the Humid Continental-Warm Summer climatic zone. This type of climate has a characteristic long, warm summer with moderate relative humidity. The winters are cool to cold and mark a period of lower precipitation than during the remainder of the year. Because of its geographical location far inland, the region is subject to significant seasonal and daily temperature variations. Air masses moving over the state during the year include cold continental polar air from Canada, warm and humid maritime tropical air from the Gulf of Mexico and the Caribbean Sea, and dry eastward flowing air masses from the Rocky Mountains located to the west. Prolonged periods of extreme hot or cold temperatures are unusual (MU, 2006).

The general geostrophic airflow pattern and the prevailing jet stream track shuttle precipitation-producing mid-latitude cyclones (lows) across the state from west-to-east throughout the year. Consequently, precipitation events in all seasons move through from a westerly direction (MU, 2006).

Spring, summer, and early fall precipitation occurs in the form of rain and thunderstorms. Severe thunderstorms typically occur during the period from mid- to late-spring through early summer. Hail may be expected as a product of these storms. Wind speeds of up to 97 km/hr (60 mi/hr) or more may be experienced once or twice a year during a severe thunderstorm (MU, 2006).

Winter precipitation is generally light to moderate and occurs in the form of rain or snow, or a mixture of both, with an occasional, though infrequent, thunderstorm. Occasional heavy snowfall episodes do occur, but not often, and the accumulation does not last for any significant duration. Surface temperature conditions sometimes produce freezing rain or drizzle, although normally not more than a couple times each season.

The historical climate data within this section primarily came from National Oceanic and Atmospheric Administration (NOAA) High Plains Regional Climate Center's historical climate data summaries for Columbia reporting stations 231790 and 231791. MU also has a weather station at South Farm, less than 1.6 km (1 mi) away from the proposed site and approximately 6.4 km (4 mi) from Columbia. The weather station is used in conjunction with the school's agricultural program, and the weather data is available on the MU website. Simple searches and averages can be obtained through this database. Other sources, as needed, were used to augment NOAA data, particularly to better understand the immediate area around the proposed RPF site.

2.3.1.1 Temperature

Though temperatures reached a record high in 2012 of 41.7°C (107°F), in general, temperatures rarely exceed 38°C (100°F) in the summer and rarely fall below -18°C (0°F) in the winter. The mean maximum temperatures in Columbia, collected from the reporting station at the Columbia Regional Airport (Station 231791) over a 43-year period ranged from 2.8°C (37.2°F) in January to 31.4°C (88.5°F) in July. Daily temperatures during that period showed a wider variance, from -28.8°C (-20°F) in December to 44°C (111°F) in July. A summary of average and extreme temperature data for 1969 through 2012 is provided in Table 2-25 (WRCC, 2013a).

Table 2-25. Columbia, Missouri, Average and Extreme Monthly Climate, Historic Temperature Summary, 1969–2012

Measurement		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average max. temperature	°C	2.9	6.1	12.7	18.9	23.6	28.5	31.4	30.7	26.0	19.6	12.0	5.1	18.1
	°F	37.2	43.0	54.9	66.1	74.4	83.3	88.5	87.3	78.8	67.2	53.6	41.2	64.6
Average min. temperature	°C	-6.8	-4.3	1.2	6.8	12.1	17.0	19.6	18.4	13.7	7.4	1.5	-4.3	6.8
	°F	19.7	24.2	34.2	44.3	53.7	62.6	67.2	65.2	56.7	45.3	34.7	24.2	44.3
Daily extreme high	°C	23.3	27.8	29.4	32.2	33.3	[a]89	43.9	43.3	38.3	34.4	28.3	24.4	43.9
	°F	74.0	82.0	85.0	90.0	92.0	[a]107	111.0	110.0	101.0	94.0	83.0	76.0	111.0
Daily extreme low	°C	-28.3	-26.1	-20.6	-7.2	-1.7	4.4	8.9	5.6	0.0	-5.6	-17.8	-28.9	-28.9
	°F	-19.0	-15.0	-5.0	19.0	29.0	40.0	48.0	42.0	32.0	22.0	0.0	-20.0	-20.0
Average mean	°C	-1.9	0.9	6.9	12.9	17.8	22.8	25.4	24.6	19.9	13.5	6.7	0.4	12.5
	°F	28.5	33.6	44.5	55.2	64.1	73.0	77.8	76.3	67.8	56.3	44.1	32.7	54.5

Source: WRCC, 2013a, "Period of Record General Climate Summary – Temperature, 1969 to 2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?mo1791, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

[a] Occurred during 2008–2012 time period.

Average temperature data for the Columbia Missouri weather station was reviewed for the most recent five years that data were available (2008 to 2012). The lowest average temperature was -4.1°C (24.65°F), recorded in January 2010, and the highest average temperature was 29.5°C (85.06°F), recorded in July 2012. The five-year annual average temperature was 13.1°C (55.58°F). A five-year temperature summary is presented in Table 2-26 (WRCC, 2013b).

Table 2-26. Columbia, Missouri, Five-Year Temperature Summary, 2008–2012

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2008	°C	-0.6	-0.9	6.1	11.6	17.1	23.3	24.7	22.8	19.0	16.0	2.4	-1.1	12.2
	°F	31.0	30.3	42.9	52.9	62.8	73.9	76.4	73.0	66.3	60.9	36.3	30.1	54.0
2009	°C	-3.1	2.4	8.1	11.7	17.9	23.3	22.5	21.9	18.6	10.2	9.8	-1.1	11.8
	°F	26.5	36.3	46.5	53.1	64.2	73.9	72.5	71.4	65.5	50.3	49.6	30.0	53.3
2010	°C	-4.1	-2.7	7.4	16.1	18.0	24.6	25.6	25.5	19.8	14.8	7.6	-1.6	12.6
	°F	24.7	27.1	45.3	60.9	64.4	76.2	78.0	77.9	67.6	58.6	45.7	29.1	54.6
2011	°C	-3.9	-0.1	6.6	14.0	16.9	24.0	27.5	24.9	17.6	14.2	8.9	3.1	12.8
	°F	24.9	31.9	43.9	57.2	62.5	75.1	81.6	76.7	63.7	57.5	48.1	37.5	55.0
2012	°C	1.7	4.3	14.9	15.0	21.6	25.0	29.5	25.8	19.6	12.0	7.7	7.5	16.1
	°F	35.0	39.7	58.8	59.0	70.9	77.1	85.1	78.5	67.3	53.6	45.8	45.5	61.0
Mean	°C	-2.0	0.6	8.6	13.7	18.3	24.0	25.9	24.2	18.9	12.8	8.5	-0.2	13.1
	°F	28.4	33.1	47.5	56.6	64.9	75.3	78.7	75.5	66.1	55.0	47.3	31.7	55.6

Source: WRCC, 2013b, "Station Monthly Time Series, Columbia, Missouri, 2008-2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/wea_mnsimts.pl?laKCOU, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

The five-year average temperature, for the same time period, reported at the MU South Farm weather station was 12.3°C (54.2°F). The average minimum temperature was 6.9°C (44.5°F) and the average maximum temperature was 17.9°C (64.3°F) (MU, 2013).

2.3.1.2 Precipitation

According to the historical data from Station 231791, precipitation in the Columbia, Missouri area averages approximately 103.1 cm (40.6 in.) per year. Of that amount, the mean snowfall is 57.7 cm (22.7 in.) per year. The city has measurable amounts of precipitation 111 days/year. The maximum annual precipitation of 159 cm (62.49 in.) was measured in 1993, and the minimum annual precipitation of 60 cm (23.66 in.) was measured in 1980. On a monthly basis, rainfall amounts range from a high of 12.4 cm (4.89 in.) in May to a low of 4.62 cm (1.82 in.) in January (WRCC, 2013a). The maximum probably precipitation in a one-hour period is 3.14 in./hr (NOAA Atlas 14, *Precipitation-Frequency Atlas of the United States*).

According to the historical data from Station 231791, snow falls from November through April. During that period, a high of 16 cm (6.3 in.) was recorded in February 2011, and a low of 1.5 cm (0.6 in.) was recorded in 1980. A summary of average and extreme precipitation data for 1969 through 2012 is provided in Table 2-27 (WRCC, 2013a).

A recent five-year precipitation summary of the station data was obtained and reviewed. For each month during this time period, approximately 15 to 30 percent of the data was missing. Precipitation data from the MU South Farm weather station was also reviewed; however, the averages shown on the site were different than the Columbia weather station by a factor of five. Thus, the Columbia, Missouri weather station historical summary serves as the more complete picture of precipitation at the proposed RPF site.

Table 2-27. Columbia, Missouri, Average and Extreme Monthly Climate, Historic Precipitation Summary, 1969–2012

Measurement		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average total precipitation	cm	4.62	5.44	8.10	11.23	12.42	10.24	9.58	10.06	9.53	8.28	7.72	6.02	103.12
	in	1.82	2.14	3.19	4.42	4.89	4.03	3.77	3.96	3.75	3.26	3.04	2.37	40.60
High	cm	15.09	15.70	25.63	29.69	31.27	26.11	30.84	25.88	30.63	[a]27.9	26.47	17.68	158.72
	in	5.94	6.18	10.09	11.69	12.31	10.28	12.14	10.19	12.06	[a]10.99	10.42	6.96	62.49
Low	cm	0.13	0.28	1.98	2.26	[a]3.33	0.89	0.61	0.53	1.14	[a]0.91	1.07	1.22	60.10
	in	0.05	0.11	0.78	0.89	[a]1.31	0.35	0.24	0.21	0.45	[a]0.36	0.42	0.48	23.66
1-day max	cm	4.47	6.10	9.98	11.43	12.14	8.15	15.09	10.85	7.11	12.40	7.04	6.88	15.09
	in	1.76	2.40	3.93	4.50	4.78	3.21	5.94	4.27	2.80	4.88	2.77	2.71	5.94
Average total snowfall	cm	15.75	[a]16.00	7.37	1.52	0.00	0.00	0.00	0.00	0.00	0.00	4.57	12.70	57.66
	in	6.20	[a]6.3	2.90	0.60	0.00	0.00	0.00	0.00	0.00	0.00	1.80	5.00	22.70
High snowfall	cm	59.69	59.18	54.86	18.03	0.00	0.00	0.00	0.00	0.00	0.25	21.08	45.21	134.11
	in	23.50	23.30	21.60	7.10	0.00	0.00	0.00	0.00	0.00	0.10	8.30	17.80	52.80

Source: WRCC, 2013a, "Period of Record General Climate Summary – Temperature, 1969 to 2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?mo1791, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

[a] Occurred during 2008–2012 time period.

Hydrometeorological Report No 51, *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian* (NOAA, 1978) provides probable maximum precipitation data for the U.S. east of the Rocky Mountains. Probable maximum precipitation values for a specific location are provided in Table 2-28 over ranges of time (6 to 72 hr) or ranges of geographic area (10 mi^2 to 20,000 mi^2).

Table 2-28. 72-Hour Probable Maximum Precipitation

Area	Precipitation (in.)				
	6-hr	12-hr	24-hr	48-hr	72-hr
10 mi^2	28	33	37	38.5	40
200 mi^2	20	24.5	26	29.5	33
1,000 mi^2	15	18.5	20.5	24	25.5
5,000 mi^2	9	12	14	17	19
10,000 mi^2	7	9.5	11.5	15	16.5
20,000 mi^2	5.1	7.5	9.5	12.5	14

2.3.1.3 Maximum Probable Snowpack

NUREG-1537, Part 1, Section 2.3.1, states that the snow load should be based on the 100-year return period snow accumulation. For MU facilities, the 2012 International Building Code (IBC) (IBC, 2012) has been levied as the required building code. The ground snow load is 20 lb/ft^2. To modify the snow load to be based on a 100-year return period, an importance factor of 1.2 is applied to the load determined using the nominal snow load (ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures*, Section C7.3.3). The nominal ice thickness is 2.54 cm (1 in.) concurrent with a 64.4 km/hr (40-mi/hr), 3-sec wind gust. To modify the ice load to be based on a 100-year return period, an importance factor of 0.82 is applied to the load determined using the nominal ice load (ASCE 7-10, Section C10.4.4).

2.3.1.4 Humidity

Average relative humidity data for the Columbia, Missouri weather station was reviewed for 2008 to 2012. The lowest average relative humidity was 51.89 percent, recorded in August 2012, and the highest average relative humidity was 82.13 percent, recorded in September 2008. The five-year annual average was 69.18 percent. The five-year relative humidity data is summarized in Table 2-29 (WRCC, 2013b).

Table 2-29. Relative Humidity Data for Columbia, Missouri, 2008–2012

Year	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Oct (%)	Nov (%)	Dec (%)	Annual (%)
2008	60.51	72.02	66.68	64.85	69.49	71.40	74.38	78.87	82.13	77.52	65.87	71.48	71.18
2009	64.95	63.73	63.28	66.52	68.42	73.66	74.46	76.90	75.92	76.62	68.08	72.33	70.41
2010	75.69	73.42	70.33	61.24	74.71	76.64	79.19	75.19	76.17	58.65	64.86	72.85	71.58
2011	71.86	71.51	71.26	64.73	74.61	72.69	76.29	75.19	70.82	59.46	71.92	74.84	71.27
2012	64.05	63.72	63.58	65.03	61.33	54.89	52.96	51.89	69.64	66.76	62.25	70.91	61.46
Mean	67.41	68.88	67.03	64.47	69.71	69.86	71.46	71.61	74.94	65.37	66.78	72.88	69.18

Source: WRCC, 2013b, "Station Monthly Time Series, Columbia, Missouri, 2008-2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/wea_mnsimts.pl?laKCOU, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

2.3.1.5 Wind

Extreme wind speeds are uncommon in central Missouri. Wind that does occur is usually caused by pressure gradients and temperature contrasts present in the mid-latitude cyclones that pass through the state. These cyclones may spawn storms that produce high winds from gust fronts, microbursts, and tornadoes. Non-storm-related extreme winds are rare. Occasionally, cold high-pressure air filling in behind a front will cause high wind, especially in the winter when temperature contrasts are large.

Average wind speed data for the Columbia, Missouri weather station was reviewed for 2008 to 2012. The lowest mean wind speed was 8.8 km/hr (5.47 mi/hr) in August 2008 and the highest was 19.1 km/hr (11.87 mi/hr) recorded in December 2008. The five-year annual average was 14.25 km/hr (8.86 mi/hr). The five-year mean wind speed data is summarized in Table 2-30.

Table 2-30. Mean Wind Speed for Columbia, Missouri, from 2008–2012

Year	Rate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2008	(km/hr)	18.85	17.03	16.96	17.53	15.76	13.97	11.28	8.80	10.01	11.59	14.32	19.10	14.93
	(mi/hr)	11.71	10.58	10.54	10.89	9.79	8.68	7.01	5.47	6.22	7.20	8.90	11.87	9.28
2009	(km/hr)	15.24	17.96	18.31	17.99	12.38	12.47	10.32	11.91	10.40	14.58	14.71	17.03	14.44
	(mi/hr)	9.47	11.16	11.38	11.18	7.69	7.75	6.41	7.40	6.46	9.06	9.14	10.58	8.97
2010	(km/hr)	13.74	13.73	15.96	17.06	12.79	11.43	10.06	9.88	12.17	16.30	14.73	13.41	13.10
	(mi/hr)	8.54	8.53	9.92	10.60	7.95	7.10	6.25	6.14	7.56	10.13	9.15	8.33	8.14
2011	(km/hr)	13.63	16.87	17.08	18.49	15.14	14.45	10.09	10.38	11.89	13.66	18.88	14.15	14.56
	(mi/hr)	8.47	10.48	10.61	11.49	9.41	8.98	6.27	6.45	7.39	8.49	11.73	8.79	9.05
2012	(km/hr)	16.98	15.64	16.53	15.19	13.42	13.68	10.56	11.35	11.57	13.79	14.97	14.18	13.97
	(mi/hr)	10.55	9.72	10.27	9.44	8.34	8.50	6.56	7.05	7.19	8.57	9.30	8.81	8.68
Mean	(km/hr)	15.69	16.24	16.96	17.25	13.90	13.20	10.46	10.46	11.20	14.08	15.92	16.25	14.26
	(mi/hr)	9.75	10.09	10.54	10.72	8.64	8.20	6.50	6.50	6.96	8.75	9.89	10.10	8.86

Source: WRCC, 2013b, "Station Monthly Time Series, Columbia, Missouri, 2008-2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/wea_mnsimts.pl?laKCOU, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

Wind data from the MU South Farm weather station was also reviewed. The average shown on the site was different than the Columbia weather station by a factor of two. Thus, the Columbia weather station data serves as the more complete picture of wind activity at the proposed RPF site.

Two wind roses are presented to show the general historic wind flow patterns in the immediate area and the study area. Figure 2-31 shows the wind pattern as measured at MU South Farm, located immediately north of the proposed RPF site. This data is collected by MU. Figure 2-32 shows the wind patterns recorded at the Remote Automatic Weather Station (RAWS) in Columbia.

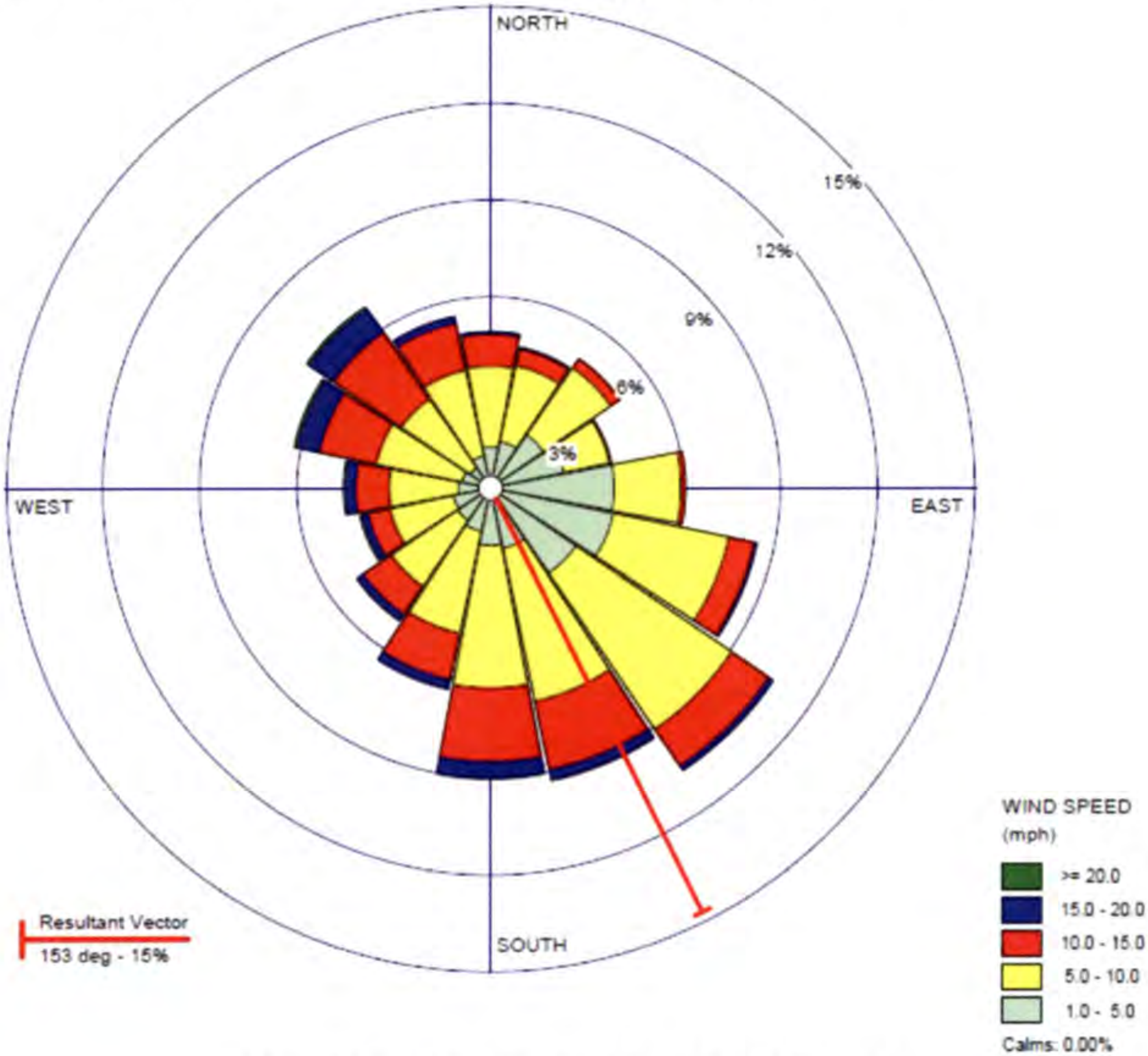

Figure 2-31. Wind Rose from South Farm, 2000–2010 (University of Missouri Agricultural Experiment Station)

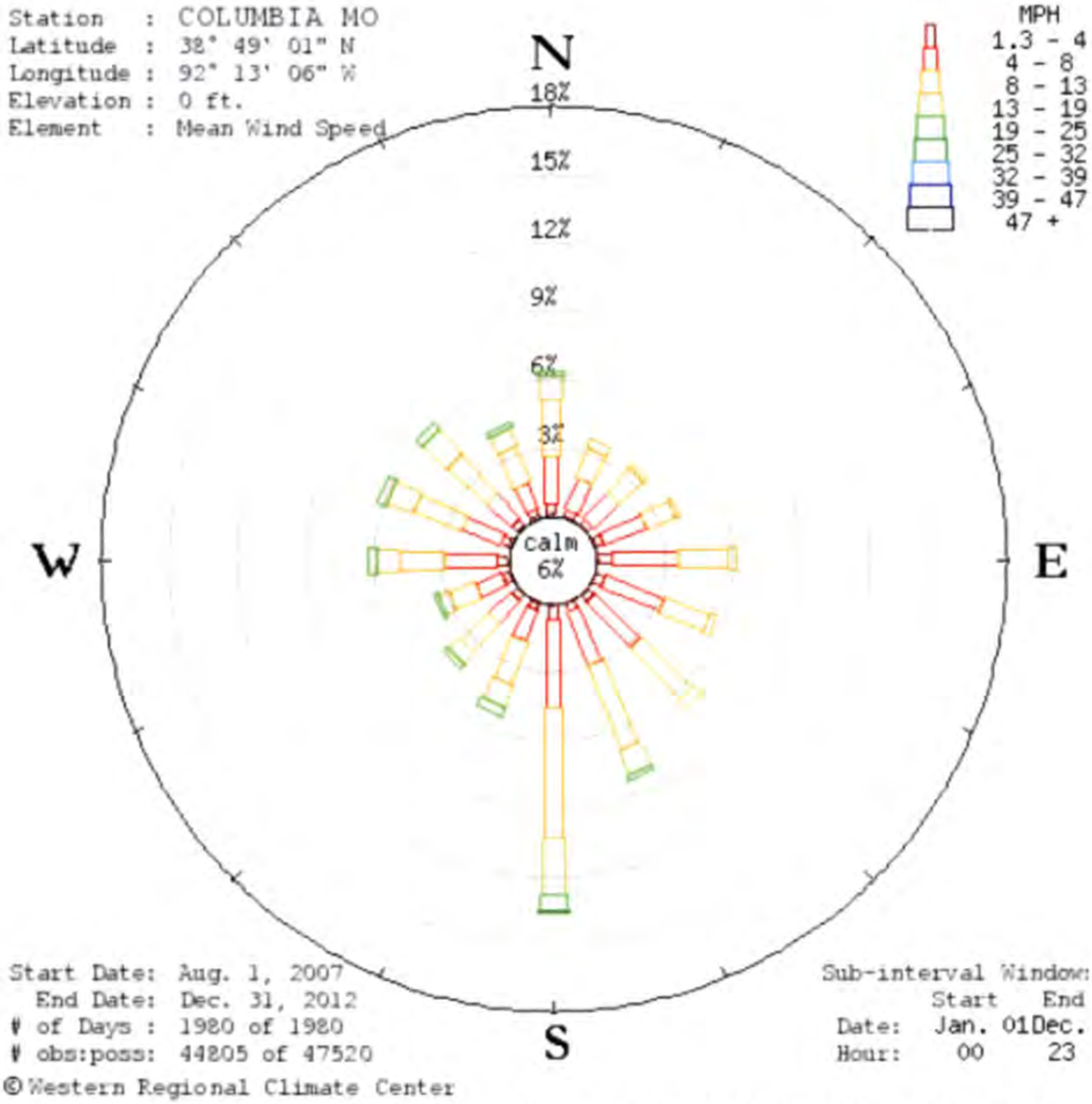

Figure 2-32. Wind Rose from Automatic Weather Station, Columbia, Missouri, 2007-2012 (Western Regional Climate Center)

Both wind roses show that the prevailing surface wind direction is from the south. The MU South Farm wind rose shows a total average wind speed of 11.3 km/hr (7 mi/hr), while the Columbia wind rose shows a total average speed of 14.16 km/hr (8.8 mi/hr). Both wind roses show that the average frequency of higher speed winds falls into the 24 to 40 km/hr (15 to 25-mi/hr) range.

2.3.1.6 100-Year Return Wind Speed

NUREG-1537, Part 1, Section 2.3.1, states that the wind load should be based on the 100-year return period wind speed. For MU facilities, IBC (2012) has been levied as the required building code. The basic wind speed for Category III and IV facilities is 193.1 km/hr (120 mi/hr). An evaluation of the effective return period for the basic wind speeds for Category III and IV facilities determined that the effective return period is 1,700 years (3 percent in 50 years, or 5.7 percent in 100 years) (ASCE 7-10, Section C26.5.1). Note that an event with a 100-year return period has a 63 percent chance of occurring at least once in a 100-year period.

2.3.1.7 Extreme Weather

The heartland of the country has the distinction of also being known as "tornado alley," a non-meteorological term that references the area where 90 percent of tornadoes have occurred as a result of the mixing of cold, dry air from Canada and the Rocky Mountains, with warm, moist air from the Gulf of Mexico and hot, dry air from the Sonoran Desert. This area exhibits a lot of atmospheric instability, heavy precipitation, and many intense thunderstorms.

Tornados are extreme wind speed events that are classified according to the Enhanced Fujita Tornado Intensity Scale (EF scale). The scale matches wind speeds to the severity of damaged caused by a tornado. The process involves determining the degree of damage according to a predefined damage scale of 28 indicators. The observed damage is associated with estimated wind speeds during the storm, and an EF scale number is assigned. Measuring tornadoes from EF-1 to EF-5, the scale uses more specific structural damage guidelines than the original Fujita scale (F scale), which was established in 1971. Table 2-31 shows the F and EF scales.

Table 2-31. Fujita Scale and Enhanced Fujita Scales Used to Determine Tornado Intensity

	F scale					EF scale	
	Fastest 1/4-mi		3-sec gust			3-sec gust	
F number	(km/hr)	(mi/hr)	(km/hr)	(mi/hr)	EF number	(km/hr)	(mi/hr)
0	64 -116	40–72	72-126	45–78	0	105-137	65-85
1	117 – 180	73–112	127-188	79–117	1	138-177	86–110
2	182- 253	113–157	189-259	118–161	2	178-217	111–135
3	254- 333	158–207	260-336	162–209	3	218-265	136–165
4	334- 418	208–260	337-420	210–261	4	266-322	166–200
5	419 – 512	261–318	421-510	262–317	5	Over 322	Over 200

EF scale = enhanced Fujita tornado intensity scale.
F scale = Fujita tornado intensity scale.

The seasonal and annual frequencies of tornadoes, thunderstorms, lighting, and hail are provided in Table 2-32 through Table 2-38.

Table 2-32. Seasonal Frequency of Historical Tornadoes in Boone County, Missouri (1954 to 2016)

Month	Magnitude (Fujita Scale)			
	F0	F1	F2	F3
January	1	-	-	-
February	1	-	-	-
March	-	2	-	-
April	1	2	5	-
May	1	1	2	-
June	1	1	-	-
July	2	1	-	-
August	-	-	-	-
September	-	2	-	-
October	2	1	-	-
November	-	-	-	3
December	1	1	1	-

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Table 2-33. Annual Frequency of Historical Tornadoes in Boone County, Missouri (1954 to 2016)

Year	Magnitude (Fujita Scale)				Total
	F0	F1	F2	F3	
1954	-	-	3	-	3
1956	-	-	1	-	1
1959	2	1	-	-	3
1965	1	-	-	-	1
1966	-	1	-	-	1
1972	-	1	-	-	1
1973	1	1	1	-	3
1980	-	-	1	-	1
1982	1	1	-	-	2
1984	-	3	-	-	3
1985	-	1	-	-	1
1987	1	-	-	-	1
1990	-	-	-	2	2
1992	1	1	-	-	2
1995	1	-	-	-	1
1998	-	-	-	1	1
1999	-	-	2	-	2
2000	1	1	-	-	2
2001	1	-	-	-	1

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Table 2-34. Boone County Seasonal Thunderstorm Wind Events (8/29/1955 to 5/11/2016)

Month	Wind Velocity (mph)								
	70-74	75-79	80-84	85-89	90-94	95-99	100-104	105-109	110-114
January	-	2	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-
March	-	8	1	3	2	-	-	-	-
April	-	12	5	2	2	-	-	1	-
May	-	13	7	9	3	2	1	1	2
June	-	20	3	6	3	1	1	2	-
July	-	12	8	10	6	1	2	2	-
August	1	18	6	2	3		1	1	-
September	-	4	1	3	-	-	-	-	-
October	-	-	-	-	-	-	-	-	-
November	-	-	1	-	-	-	-	1	-
December	-	2	-	-	-	-	-	-	-

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Table 2-35. Boone County Annual Thunderstorm Wind Events (8/29/1955 to 5/11/2016)

Year	Events	Year	Events	Year	Events	Year	Events
1956	1	1971	1	1987	2	2002	6
1957	-	1972	-	1988	2	2003	-
1958	3	1973	1	1989	-	2004	8
1959	-	1974	-	1990	3	2005	7
1960	-	1975	1	1991	1	2006	11
1961	3	1977	1	1992	1	2007	8
1962	-	1978	1	1993	-	2008	6
1963	2	1979	-	1994	2	2009	6
1964	-	1980	-	1995	5	2010	6
1965	-	1981	7	1996	2	2011	15
1966	2	1982	16	1997	1	2012	1
1967	3	1983	1	1998	9	2013	-
1968	-	1984	3	1999	1	2014	5
1969	1	1985	-	2000	17	2015	4
1970	1	1986	3	2001	6	2016	2

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Table 2-36. Boone County Lightning Events (7/5/1998 to 6/30/2016)

Location	Date	Description
Columbia	7/5/1998	Lightning strike was blamed for a fire at a residence in southwest Columbia. Firefighters arrived to find flames shooting through a hole in the roof.
Columbia	5/22/2002	A fire started by lightning destroyed 50 percent of a home in Columbia.
Columbia	8/25/2004	Lighting strike melted power lines at Providence and Green Meadows roads. About 5,000 people were affected by the resulting power outage, including New Haven Elementary School.
Columbia	8/25/2004	Lightning strike started a house fire.
Columbia	6/6/2005	Lightning strike started a house fire.
Columbia	8/26/2006	Five radio stations were knocked off the air when lightning struck a Cumulus Broadcasting transmitter tower. Control boards in the studios, computers, and magnetic door locks in the building were also damaged by the strike.
Columbia	7/19/2007	Lightning strike started a fire at a photography studio.
Sapp	4/23/2008	Lightning strike started a house fire.
Columbia	5/30/2008	Lightning strike started a house fire.
COU Memorial Airport	6/13/2008	Lightning strike started a house fire.
Browns	6/17/2009	Lightning strike killed woman in an open field at Rocky Fork Lakes Conservation Area.
Harg	7/3/2011	Lightning strike started a house fire.
Columbia	7/23/2011	Lightning struck cell phone being used by woman in Cosmo Park.

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Table 2-37. Boone County Seasonal Hail Events 4/23/1958 - 5/11/2016

	Diameter (in.)											
Location	0.75	0.88	1.00	1.25	1.50	1.75	2.00	2.50	2.75	3.00	4.00	Total
January	2	1	3	-	-	-	-	-	-	-	-	9
February	1	-	-	-	-	-	-	-	-	-	-	1
February	-	-	1	-	-	-	-	-	-	-	-	1
March	18	4	20	2	3	11	1	1	-	1	-	61
April	21	6	18	4	3	15	2	-	3	-	-	72
May	33	21	21	2	3	22	1	-	1	-	1	105
June	15	8	9	3	1	12	1	-	-	-	-	49
July	5	1	3	-	-	2	-	-	-	-	-	11
August	1	1	2	-	1	1	-	-	-	-	-	6
September	8	2	4	-	1	3	-	-	1	-	-	19
October	-	-	-	-	-	1	-	-	-	-	-	1
November	1	2	5	-	-	3	-	-	2	-	-	13
December	-	2	2	-	-	1	-	-	-	-	-	5

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Table 2-38. Boone County Annual Hail Events 4/23/1958 - 5/11/2016

Year	Events	Year	Events	Year	Events	Year	Events
1958	1	1972	-	1987	1	2002	13
1959	1	1973	3	1988	5	2003	13
1960	1	1974	6	1989	1	2004	-
1959	1	1975	1	1990	4	2005	36
1961	1	1976	2	1991	5	2006	49
1962	2	1977	1	1992	7	2007	5
1963	1	1978	-	1993	4	2008	19
1964	-	1979	-	1994	3	2009	11
1965	1	1980	1	1995	10	2010	7
1966	2	1981	4	1996	5	2011	21
1967	1	1982	15	1997	1	2012	8
1968	3	1983	1	1998	3	2013	8
1969	1	1984	15	1999	7	2014	9
1970	2	1985	2	2000	13	2015	3
1971	-	1986	2	2001	10	2016	2

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

Winter weather events since 1996 in Boone County, Missouri, are provided in Table 2-39. These events include snowstorms, ice storms, and extreme cold events. The RPF is being designed to ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, to withstand expected meteorological events. This information will be factored in the design requirements of Section 3.2.5, "Rain, Snow, and Ice Loading," for the RPF.

Table 2-39. Boone County Winter Weather Events (1/1/1996 to 6/30/2016) (2 pages)

Date	Storm type	Duration (days)	Description
1/2/96	Winter storm	1	6-9 inches of snow in region
1/3/96	Winter storm	2	2-4 inches of snow in region
11/25/96	Ice storm	1	Numerous traffic accidents
1/8/97	Winter storm	2	5-7 inches of snow, strong winds, very cold temperatures
1/15/97	Winter storm	2	Freezing rain and sleet with ¼ to ½ in. of ice accumulation followed by 3 to 8 in. of snow in the region
1/27/97	Winter storm	1	Freezing rain with ½ to 1 in. of ice accumulation
4/10/97	Winter storm	1	2 to 6 in. of snow in the region
12/8/97	Winter storm	1	2 to 4 in. of snow in region
1/12/98	Winter storm	1	Freezing drizzle resulting in thin glaze of ice on roads
3/8/98	Winter storm	2	4 to 6 in. of snow in region
12/21/98	Winter storm	2	Light freezing drizzle, sleet, and snow left a thin coating of ice on roads
1/1/99	Winter storm	2	6 to 10 in. of snow across region with about an inch of freezing rain and sleet; very cold temperatures

Table 2-39. Boone County Winter Weather Events (1/1/1996 to 6/30/2016) (2 pages)

Date	Storm type	Duration (days)	Description
1/27/00	Winter storm	3	4 to 5 in. across region
3/11/00	Winter storm	1	4 to 7 in. of snow
12/13/00	Heavy snow	1	6 to 12 in. across region
12/16/00	Extreme cold/wind chill	2	Wind chills from -20°F to -40°F
1/29/02	Ice storm	2	1¼ to ½ in. of ice accumulation; power outages
3/2/02	Winter storm	1	½ in. of sleet followed by 4 to 6 in. of snow; winds of 20 to 30 mi/hr
3/25/02	Winter storm	2	Sleet followed by snow; 3- to 4-in. accumulation of the mix
12/4/02	Winter storm	1	2 to 5 in. of snow across region
12/24/02	Winter storm	1	4 to 8 in. of snow across region
1/1/03	Winter storm	2	Sleet accumulation up to 1 in. followed by 6 to 8 in. of snow across the region
2/23/03	Winter storm	2	3 to 6 in. of snow across the region
12/9/03	Winter storm	2	3 to 5 in. of snow across the region
12/13/03	Winter storm	1	3 to 6 in. of snow across the region
1/25/04	Winter storm	1	Freezing rain followed by 1 to 2 in. of sleet and then 1 to 2 in. of snow
11/24/04	Winter storm	1	4 to 6 in. of snow across region
12/8/05	Winter storm	1	2 in. of snow
11/29/06	Winter storm	3	Over a foot of snow in some areas
1/12/07	Ice storm	3	Up to 1.5 in. of sleet and ¼ to ½ in. of ice accumulation in region
12/8/2007	Ice storm	4	Up to a ½ in. of ice accumulated along with up to 1 in. of sleet
1/31/2011	Winter storm	2	Up to 20 in. of snow fell along with winds gusting over 40 mi/hr.
12/21/2013	Ice storm	1	Average ice accumulation on trees and other overhead surfaces was from 0.25 to 0.30 in; about ½ inch of sleet also fell in some locations
1/5/2014	Winter storm	1	6 to 9 in. of snow across with strong northerly winds produced snow drifts of 2 to 5 ft
2/4/2014	Winter storm	1	6 to 13 in. of snow across the region

Source: NOAA, 2016, "Storm Events Database," www.ncdc.noaa.gov/stormevents, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Washington, D.C., accessed November 2016.

2.3.2 Site Meteorology

Conservative assumptions were used, in both the Radiological Safety Analysis Computer (RSAC) code to support 10 CFR 100.11, "Determination of Exclusion Area, Low Population Zone, and Population Center Distance," analyses and the ALOHA air dispersion model to support the preliminary safety analysis report with regard to meteorological inputs and identified scenarios.

The RSAC code, Version 6.2, was used to determine if the dose rate requirements in 10 CFR 100.11 would drive the required size of the exclusion area boundary (controlled area) for the NWMI RPF. 10 CFR 100.11 requires that an exclusion area be sized so that an individual located at any point on its boundary for 2 hr immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 roentgen equivalent in man (rem).

In the preliminary safety analysis report, design-basis events and the potential effects of those accidents on the facility, in terms of design parameters (e.g., overpressure, missile energies) or physical phenomena (e.g., impact, flammable or toxic clouds) were identified in accordance with 10 CFR 20, 10 CFR 50.34, Regulatory Guide 1.78, Regulatory Guide 1.91, Regulatory Guide 1.206, Regulatory Guide 4.7, and NUREG-1537.

Design-basis events, external to the proposed RPF, are defined as those accidents that have a probability of radiological release to the public on the order of magnitude of 1E-07 per year, or greater, with the potential consequences serious enough to affect the safety of the plant to the extent that the guidelines in 10 CFR 50.34 could be exceeded.

Chemicals were evaluated to ascertain which hazardous materials had the potential to form a flammable vapor cloud or vapor cloud explosion. For those chemicals with an identified flammability range, the ALOHA air dispersion model was used to determine the distances where the vapor cloud may exist between the upper explosion limit and the LEL, presenting the possibility of ignition and potential thermal radiation effects (ALOHA, 2008).

Conservative meteorological assumptions were used in both the RSAC and ALOHA analyses. Conservative Pasquill stability classes, including F and G, along with a wind speeds of 1 to 2 m/sec were assumed for the analyses. Site-specific meteorological measurements were not necessary to complete these bounding analyses.

Table 2-40 provides a tabulation of the distance from the exhaust stacks where airborne releases might be expected to points on the fence and site boundaries in each of the 16 compass directions to support dispersion analyses of airborne releases.

Table 2-40. Distances from Exhaust Stacks to Fence and Site Boundaries

Compass direction	Fence line		Site boundary	
	m	ft	m	ft
North	29	94	76	250
North Northeast	70	231	76	250
Northeast	82	269	86	281
East Northeast	103	338	110	363
East	76	250	84	275
East Southeast	65	213	69	225
Southeast	65	213	69	225
South Southeast	72	238	76	250
South	110	363	118	388
South Southwest	95	313	156	513
Southwest	80	263	149	488
West Southwest	42	138	112	369
West	23	75	65	213
West Northwest	19	63	57	188
Northwest	19	63	57	188
North Northwest	19	63	76	250

Regional Data Sources

Meteorological measurements would be available for use in responding to accidental radiological releases, other emergencies, and any other routine purposes that require access to meteorological information during the licensing period. That meteorological information would be obtained for local government weather monitoring stations that observe wind and other surface meteorological parameters on an hourly basis.

When needed during an emergency, real-time hourly surface meteorological measurements of wind direction, wind speed, air temperature, and weather type would be accessed by NWMI through Government data sources. Access would be attempted during the emergency in the following sequence, until reliable data is obtained, as follows:

1. Internet access to hourly surface weather observations recorded at Station 231791, Columbia Regional Airport (w1.weather.gov/data/obhistory/KCOU.html).
2. Telephone access to an automated voice recording at (573) 499-1400 of the most recent hourly surface observations recorded at the Columbia Regional Airport.
3. If weather observations are not available from the station at the Columbia Regional Airport, weather information from another station with hourly meteorological data in the site climate region would be used. The following Missouri stations would be used as listed in order of increasing distance from Columbia:
    a. Jefferson City Memorial Airport: w1.weather.gov/data/obhistory/KJEF.html
    b. Kansas City International Airport: w1.weather.gov/data/obhistory/KMCI.html
    c. Sedalia Memorial Airport: w1.weather.gov/data/obhistory/KDMO.html
    d. Spirit of St. Louis Airport: w1.weather.gov/data/obhistory/KSUS.html

During normal operations, data would be obtained by internet access to hourly surface weather observations recorded at the Columbia Regional Airport at w1.weather.gov/data/obhistory/KCOU.html.

2.4 HYDROLOGY

2.4.1 Surface Water

Surface waters in central and southern Boone County drain into the Missouri River through a number of tributaries, including Bonne Femme, Cedar, Little Cedar, Hinkson, Jemerson, and Perche Creeks (Figure 2-33). The other major drainage feature in the county is a system of karst topography west and south of Columbia. Numerous sinkholes, some filled with water, overlie a complex network of caves and springs. Gans Creek, which drains Discovery Ridge and the proposed RPF site, is located within the Bonne Femme Watershed.

Bonne Femme Watershed

The Bonne Femme Watershed is comprised of two major sub-watersheds: the Bonne Femme and the Little Bonne Femme. Topographical contours of the land define the Bonne Femme Watershed, which encompasses approximately 241 square kilometers (km^2) (93 mi^2), approximately 15 percent of Boone County, including the proposed RPF site (BFSC, 2007). The RPF site is located within the northern portion of this watershed (Little Bonne Femme sub-watershed) and is approximately 0.4 km (0.25 mi) north of Gans Creek (Figure 2-34).

MDNR 2012 *Section 303d Listed Impaired Streams and Lakes* [digital data]: ftp://msdis.missouri.edu/pub/Environment_Conservation/MO_2012_Section_303d_Impaired_Lakes_shp.zip

Figure 2-33. Streams of Southern Boone County, Missouri

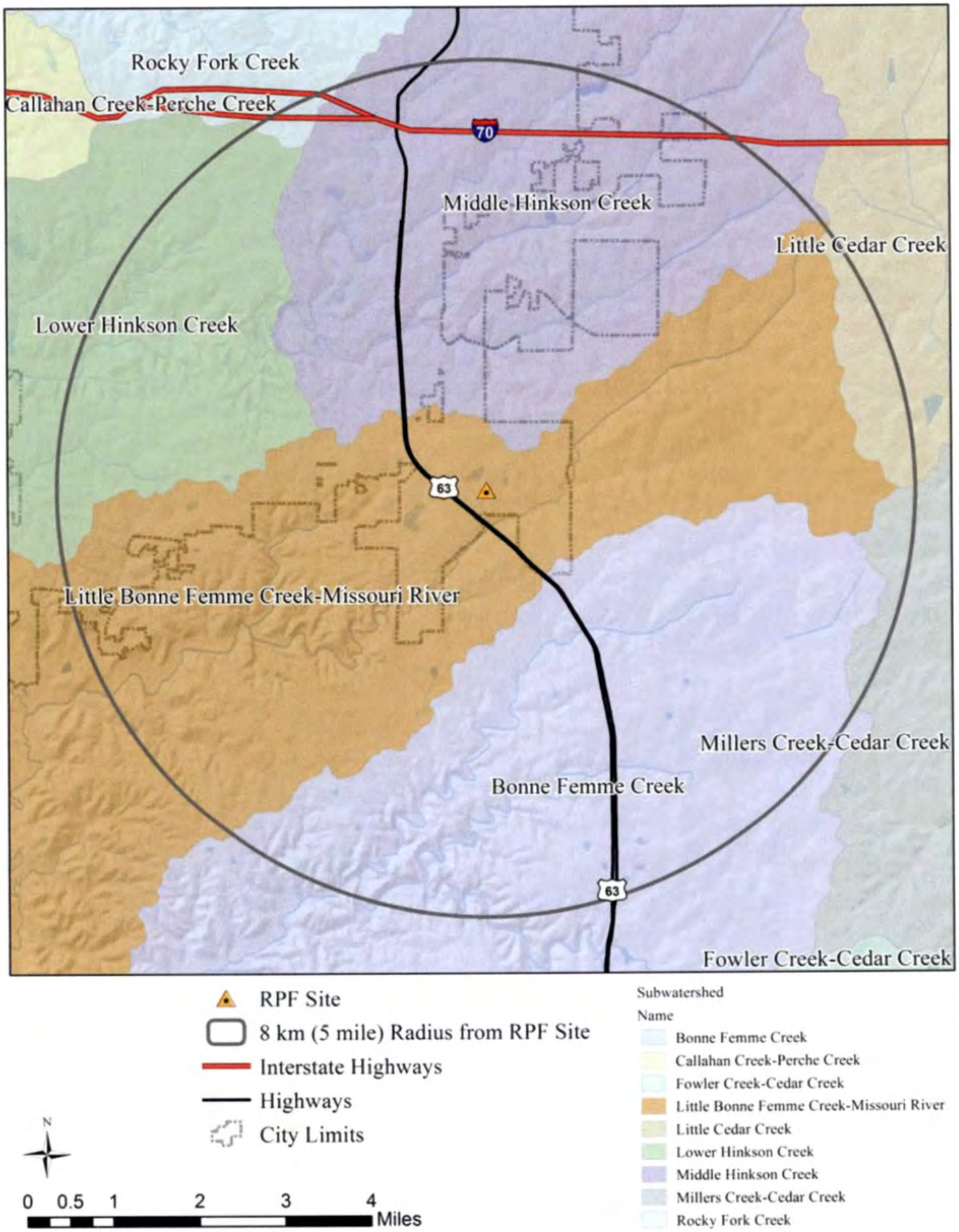

Figure 2-34. Map Showing Bonne Femme Watershed

Both the Bonne Femme and Little Bonne Femme creeks flow from east to west in a dendritic alignment into the Missouri River and are interconnected by the Devil's Icebox Cave Branch. Where Gans Creek meets Clear Creek, the Little Bonne Femme begins and flows south toward the Mayhan Branch. The Little Bonne Femme enters the Missouri River approximately 0.8 km (0.5 mi) south of this confluence. To the south, the Bonne Femme meets with the Fox Hollow Branch and then flows into the Missouri River (BFSC, 2007).

The most distinctive characteristic of the Bonne Femme Watershed is its karst topography. Within the karst terrain, the hydrology becomes complex because of losing and gaining sections of streams. Rough estimates show approximately 33 stream segments comprising approximately 37 km (23 mi) of losing streams (143 km [89 mi] of gaining stream) within the watershed. There are two main recharge areas tied to these losing and gaining sections of stream, including Devil's Ice Box recharge zone (3,397 ha [8,394 acres] of drainage), and Hunter's Cave recharge zone (3,330 ha [8,228 acres] of drainage) (BFSC, 2007).

A mixture of land uses occurs within the Bonne Femme watershed. The predominant land use accounting for 61.5 percent of the watershed is agricultural activities, including row crop productions, pasture, and range lands. Forested areas make up nearly one-third of the watershed, mainly within the central and western portion of the watershed. These forested areas also encompass most of the publicly owned lands, including Rock Bridge Memorial State Park and Three Creeks Conservation Area (BFSC, 2007).

2.4.2 Ground Water

Groundwater is the source of 74 percent of all rural domestic self-supplied water, 75 percent of all irrigation water, and 39 percent of all industrial self-supplied water, excluding water for thermoelectric power generation. The six principal aquifers in Missouri include:

- Major river valleys
- Alluvial (in southeastern Missouri)
- Wilcox and Claiborne
- McNairy
- Ozark
- Mississippian Aquifer (Kimmswick-Potosi)

The groundwater aquifer beneath the proposed RPF site is the Mississippian aquifer (also referred to as the Kimmswick-Potosi aquifer). Figure 2-35 is a map of the aquifer.

The Mississippian aquifer is the principal aquifer supplying groundwater to Boone County. The Mississippian aquifer consists of consolidated dolomite, limestone, and some sandstone beds that are generally confined. The Keokuk limestone and Burlington limestone are the principal water-yielding formations within this aquifer. Both formations consist of crystalline limestone and yield water primarily from solution cavities. In most places, the aquifer is overlain by a confining unit of Pennsylvanian shale and sandstone and glacial till. The aquifer is typically underlain by a confining unit of Mississippian shale. Recharge occurs primarily from precipitation infiltrating overlying aquifers. The top of this aquifer is approximately 548.6 m (1,800 ft) below-ground surface and is a primary source of water in seven counties north of the Missouri River (Miller and Appel, 1997).

In accordance with drillers' reports generated from 1987 to 2005, the estimated static water level in the area near the proposed site was approximately 198 m (650 ft) below-ground surface (MDNR, 2006). During previous investigations at Discovery Ridge, groundwater was observed at depths ranging from approximately 3.7–5.6 m (12–18.5 ft) below-ground surface.

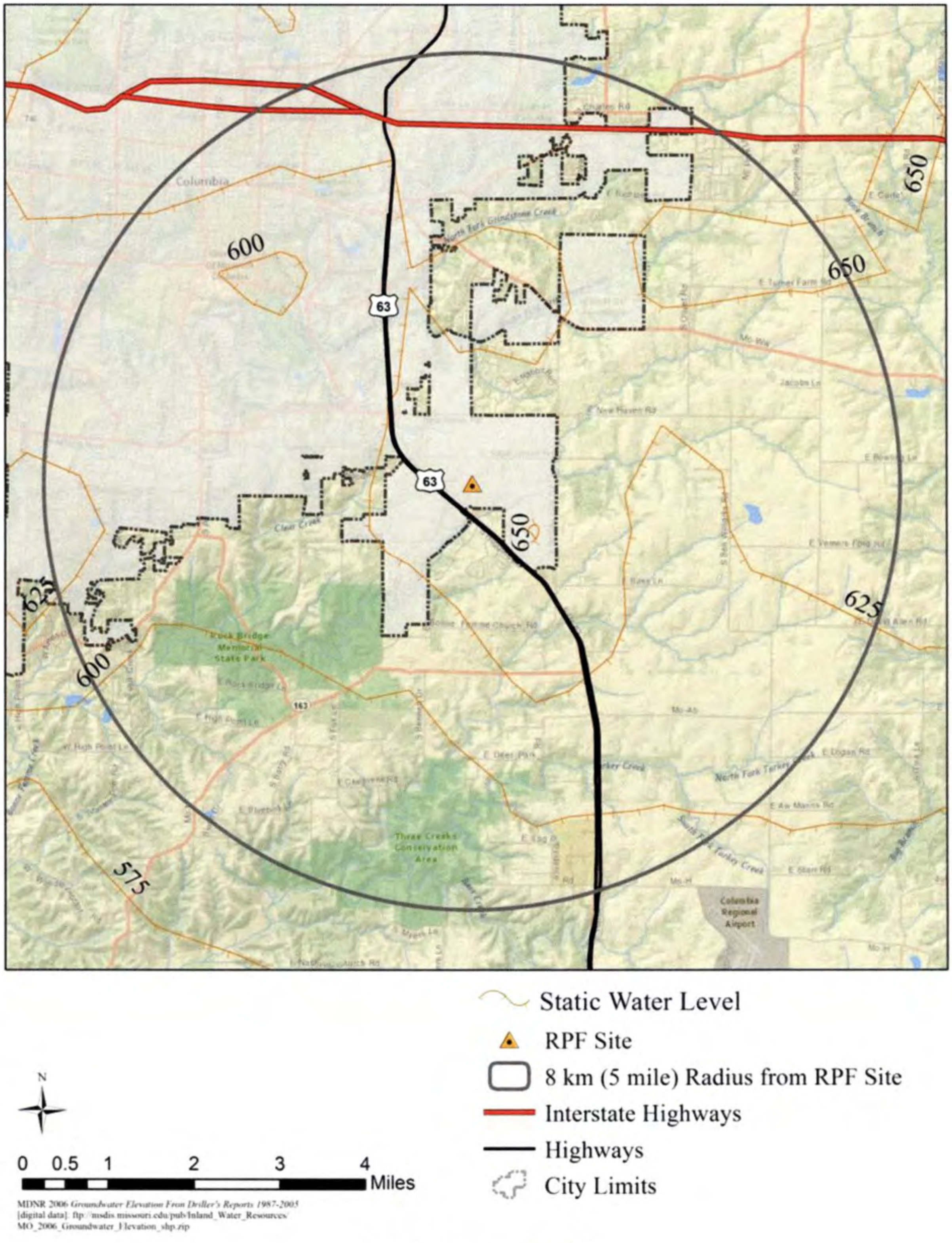

Figure 2-35. Aquifer Map

2.4.3 Floods

This subsection identifies the effects of potential floods on the proposed RPF site. Figure 2-36 provides the Federal Emergency Management Agency (FEMA) flood map of the area around the proposed RPF site. The site is located outside of the 500-year flood plain. The nearest FEMA flood zone A is located along Gans Creek located to the southeast of the site. The elevation of this zone is 242 m (795 ft). The RPF site elevation is 248 m (815 ft). There are no water impoundments or dams upstream of the RPF site on Gans Creek that could affect the facility.

There are also two ponds located near the RPF site within Discovery Ridge. These ponds include the 7.9 ha (19.6-acre) common grounds stormwater management pond located to the northwest of the site. The top of the dam for this pond is 246 m (807 ft), with the spillway at 245 m (804 ft). The second pond, currently approximately 4 ha (10 acres), is located to the northeast of the site. The elevation of the dam is approximately 244 m (801 ft). Failure of either of these two ponds would not likely affect the RPF because the elevation of the dams is lower than the elevation of the RPF.

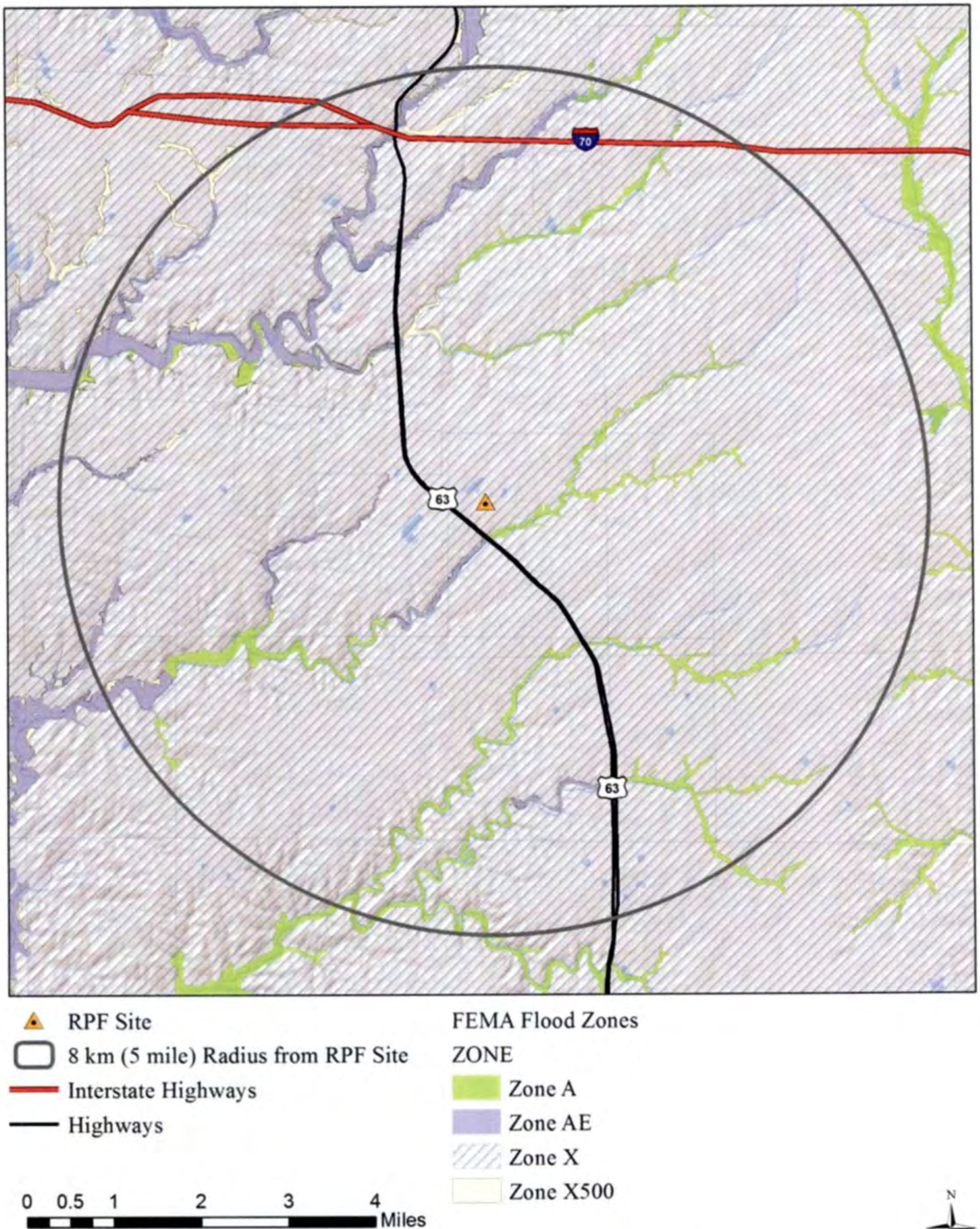

Figure 2-36. Federal Emergency Management Agency Flood Zones Around the Radioisotope Production Facility

2.5 GEOLOGY, SEISMOLOGY, AND GEOTECHNICAL ENGINEERING

This subsection provides summary descriptions of geomorphic provinces and their tectonic development, and the glacial history responsible for surface topography features found today in the state of Missouri. The descriptions are based on a review of relevant, readily available published reports and maps, and where available, records and unpublished reports from federal and state agencies. Information on the site characteristics has been acquired from these same sources and from site-specific investigations, including geotechnical field studies.

2.5.1 Regional Geology

2.5.1.1 Geomorphic Provinces

The state of Missouri is divided into three geomorphic provinces:

- Interior Plains Province, also referred to as the Central Lowland Province (northern Missouri, north of the Missouri River)
- Interior Highlands (central Missouri, south of the Missouri River)
- Atlantic Plains, also referred to as the Coastal Plains Province (the "boot heel" or southeastern corner of Missouri).

The proposed RPF site is located north of the Missouri River within the Interior Plains province. The Interior Plains are defined by the general texture of the surface terrain, rock type, and geologic structure. They are characterized by moderately dissected, glaciated, flat to rolling plains that slope gently toward the Missouri and Mississippi River valleys. Local relief is 6.1-50.3 m (20-165 ft). Drainage is dendritic, current geomorphic processes are fluvial erosion, transport and deposition, and minor mass wasting. Elevations range from 183-457 m (600-1,500 ft) above mean sea level, with the proposed RPF site averaging 245 m (805 ft) above mean sea level (USGS, 2013a).

2.5.1.1.1 Interior Plains Province

The Interior Plains Province is a vast region spread across the stable core (craton) of North America. This area formed when several small continents collided and welded together over a billion years ago, during the Precambrian Era. Precambrian metamorphic and igneous rocks now form the basement of the Interior Plains and make up the stable core of North America. Throughout the Paleozoic and Mesozoic Eras, the low lying Interior Plains remained relatively unaffected by mountain building and tectonic collisions in the western and eastern margins of the continent.

During the Mesozoic Era, the majority of the North American continental interior was above sea level, with two notable exceptions. The first occurring during the Jurassic Era (208-144 million years ago), when rising seas flooded the low-lying areas of the continent and most of the Interior Plains were eventually submerged beneath the shallow Sundance Sea. The second exception occurred during the Cretaceous Period, when record high sea levels flooded the continental interior with shallow seas. During this time, the Interior Plains continued to receive deposits from the eroding Rocky Mountains to the west and Appalachian and Ouachita-Ozark Mountains to the east and south throughout the most recent Cenozoic Era. The flatness of the Interior Plains is a reflection of the platform of mostly flat-lying marine and stream deposits laid down in the Mesozoic and Cenozoic Eras. The overlying sedimentary rocks are composed mostly of limestone, sandstone, and shales (USGS, 2013a).

2.5.1.1.2 Interior Highlands Province

The southern portion of Missouri, south of the Missouri River, is located within the Interior Highlands Province. The Interior Highlands includes the Ozark and Ouachita Mountains of southern Missouri, Arkansas, and eastern Oklahoma. The rocky outcrops that make of the core of the Interior Highlands are Paleozoic age carbonates and other sedimentary rocks that were originally deposited on the sea floor. In the Ouachita Mountains, these ancient marine rocks are now contorted by folds and faults. The ancient, eroded mountains of the Interior Highlands stand surrounded by nearly flat-lying sedimentary rocks and deposits of the Interior and Atlantic Plains provinces.

The Interior Highlands consist of thick bedrock units of sandstone and shale, with lesser amounts of chert and novaculite (a fine-grained silica rock, like flint), deposited in a deep sea that covered the area from Late Cambrian through Early Pennsylvanian time. The area was then folded and faulted in such a manner that resistant beds of sandstone, chert, and novaculite now form long, sinuous mountain ridges that tower 152-457 m (500-1,500 ft) above adjacent valleys formed in easily eroded shale (USGS, 2013a).

2.5.1.1.3 Atlantic Plains Province

The Atlantic Plain Province is the flattest of all the provinces and stretches over 3,540 km (2,200 mi) in length from Cape Cod to the border of Mexico and southward another 1,609 km (1,000 mi) to the Yucatan Peninsula. The Atlantic Plains slope gently seaward from the Interior Highlands in a series of terraces. The gentle sloping continues far into the Atlantic and Gulf of Mexico, forming the continental shelf.

Eroded sediments from the Interior Highlands were carried east and southward by streams and gradually covered the faulted continental margin, burying it under a wedge of layered sedimentary and volcanic debris thousands of feet thick. The sedimentary rock layers that lie beneath much of the coastal plain and fringing continental shelf remain nearly horizontal or tilt gently toward the sea (USGS, 2013b).

2.5.1.2 Glacial History

> *"Recent studies of ice cores, stalagmites, and other temperature dating methods have concluded that there have been 30 sustained periods of frigid temperatures in the last 3 million years. Of the classical glacial periods, only two: pre-Illinoian (Nebraskan-Kansan) and Illinoian are now recognized as having left glacial deposits in the State of Missouri. The pre-Illinoian was the most severe. Amongst its legacy was the changing of the course of the Missouri River to its present location, the scouring and filling of Northern Missouri topography, and extensive outwash gravels left to the south of the present Missouri River. Although the Ozarks were not glaciated in the recent past, a cover of Pleistocene loess of varying thicknesses extends over all of the state except for the highest parts of the Ozark Mountains. Residuum, otherwise known as soil, clay, and rock fragments degrade from exposed and subsurface bedrock. Gravity and streams move this residuum, depositing it in sometimes graded layers."* (MDNR, 2013a)

In Boone County, the glacial till averages over 43 m (140 ft) thick in the northeastern portion of the county, and the loess material reaches a maximum depth of 6.1 m (20 ft) along the Missouri River Bluffs (Boone County, 2013).

2.5.1.3 Local Topography and Soils of Boone County

The topography of Boone County ranges from highly dissected hills to flat floodplains and nearly flat uplands. Elevations range from approximately 274.3 km (900 ft) above mean sea level along the northern boundary of Boone County to about 164.6 m (540 ft) above mean sea level in the southern tip of the county. Several areas of the county contain well developed cave and sinkhole formations.

Ordovician to middle Pennsylvania-aged dolomite, limestone, sandstone, coal, and shale deposits are visible throughout Boone County in geologic outcrops and roadcuts. The Mississippian-aged Burlington limestone is easily weathered by acidic groundwater and contains some unique natural resources of Boone County, including the most famous—Devil's Ice Box cave system, which is located approximately 2.4 km (1.5 mi) southwest of the proposed RPF site. There are numerous caves in Boone County and 418 documented sinkholes (Boone County, 2013)

Pennsylvanian aged deposits are overlaid by glacial till and loess. The soils of Boone County are included in parts of two major land resource areas: the Central Claypan Area and Central Mississippi Valley Wooded Slopes.

- **Central Claypan Area** – The Central Claypan Area soils were formed in glacial till and cover the northeastern and east-central portions of Boone County. Claypan soils display extreme variability within the soil profile and across the landscape; therefore, plant growth within these soils must contend with distinctively contrasting physical, chemical, and hydrologic properties at different soil depths. The depth to the claypan soils varies from approximately 10 cm (3.9 in.) on ridge tops up to 100 cm (39.4 in.) on backslopes. The soil horizons preceding the claypan are depleted of clay minerals, cations, and have a very low pH. The claypan horizon typically has an abrupt upper boundary with 100 percent more clay than the preceding horizon, and very low permeability.
- **Central Mississippi Valley Wooded Slopes** – This major land resource area consists of a dissected glacial till plain comprising rolling narrow ridge tops and hilly-to-steep ridge slopes. The small streams in this area have narrow valleys with steep gradients. The major rivers have nearly level broad floodplains, and the valley floors are tens of meters below the adjoining hilltops. Most of the soils within the central Mississippi valley wooded slopes area are found in silty loess or glacial till, are moderately to fine-grained in texture with a mixed mineralogy, and are well drained to moderately well-drained. These soils are typically observed on ridge tops and support forest flora (Boone County, 2013).

The proposed RPF site is located in a tectonically stable Interior Plains Province.

2.5.2 Site Geology

The stratigraphy of the geologic units that underlie the proposed RPF site and/or properties within a five-mile radius from the project site (Figure 2-37), are listed below from youngest to oldest:

- Quaternary Age Holocene Series (Qal)
- Pennsylvanian Age Desmoinesian Series Marmaton Group (Pm)
- Pennsylvanian Age Desmoinesian Series Cherokee Group (Pc)
- Mississippian Age Osagean Series Burlington Formation (Mo)
- Mississippian Age Kinderhookian Series (Mk)
- Late to Early Devonian aged (D)
- Early Ordovician Age Ibexian Series (Ojc)

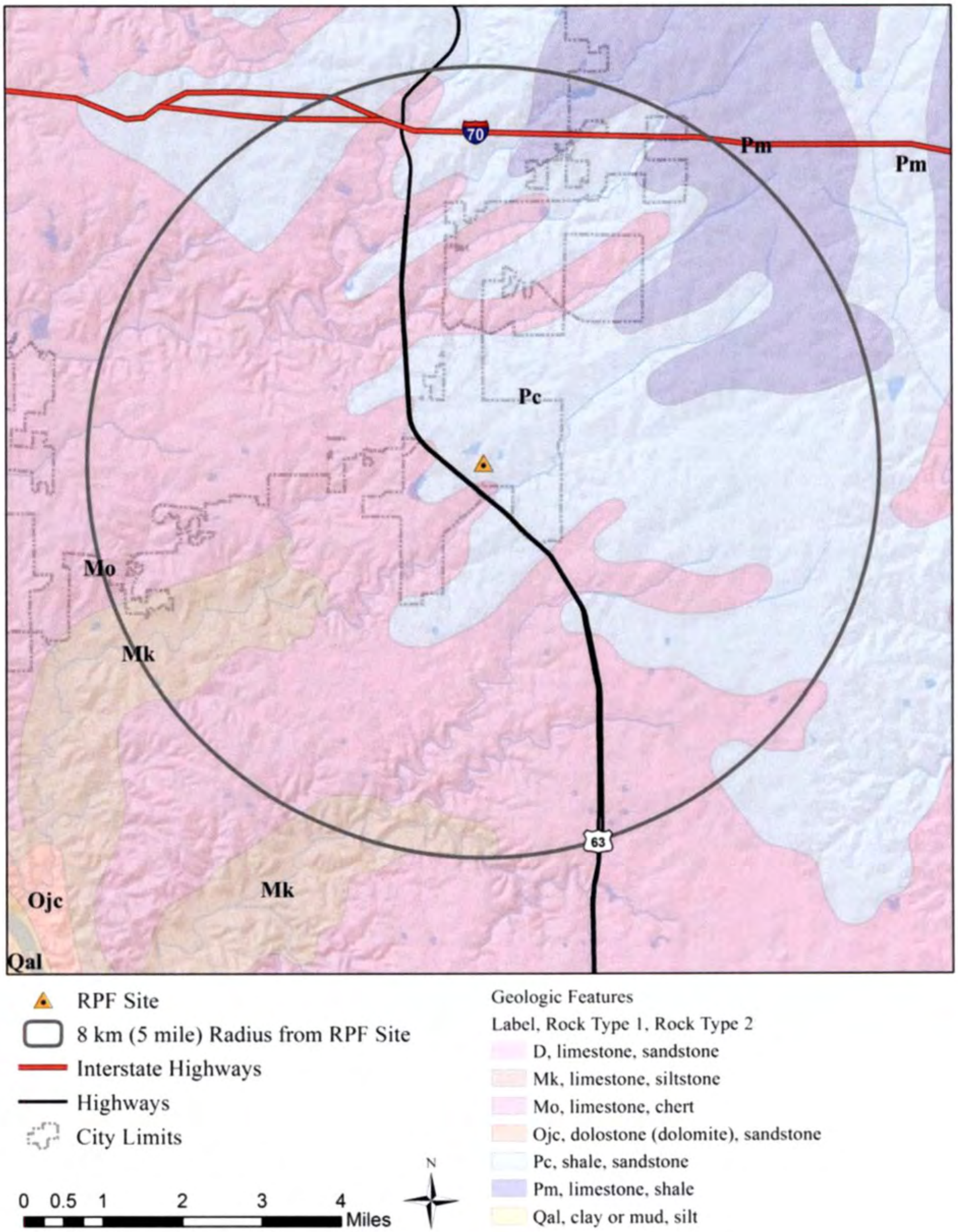

Figure 2-37. Geologic Features within an 8 km (5-mi) Radius of the Radioisotope Production Facility Site

2.5.2.1 Quaternary Age Holocene Series (Qal)

The surface topography of the proposed RPF site and surrounding properties consists of Quaternary age bedrock overburden characterized by upland areas covered by a thin loess blanket and glacial drift. Previous investigations of Discovery Ridge noted that "Highly plastic clays that exhibit volume change with variations in moisture are commonly encountered near the ground surface" (Terracon, 2011).

Figure 2-38 depicts the Quaternary age bedrock overburden at the proposed RPF site as clay loam till (No. 27). Clay loam till is also depicted on all adjacent properties to the north, east, south, and west. Additional Quaternary age deposits located within an 8 km (5-mi) radius of the proposed RPF site include alluvium (No. 10), loess (No. 18), sandy clay (No. 40), and thin, cherty clay solution residuum (No. 41).

The typical Quaternary age groundcover found in Boone County consists of alluvial (stream-deposited) clays, sand, and gravels (with a few poorly consolidated sandstones); glacial tills (sand and well-sorted gravels); and eolian (windblown) clays and loess (an extremely fine "rock flour," which forms solid masses) (MDNR, 2013b).

These glacial deposits mantle the upland areas and consist of a heterogeneous mixture of clay, sand, and pebbles of diverse rock types. The deposits vary greatly in thickness and are as much as 42.7 m (140 ft) thick in the northern portion of Boone County. This material is relatively impermeable and supplies very little water to wells (MU, 2006).

A site-specific geotechnical investigation of the RPF site will be conducted to identify specific soil characteristics. If highly plastic clays are identified at the site, the design will include excavation of the clays and then backfill with structural fill. The RPF structural design will be completed during the final design and will be included as part of the Operating License Application.

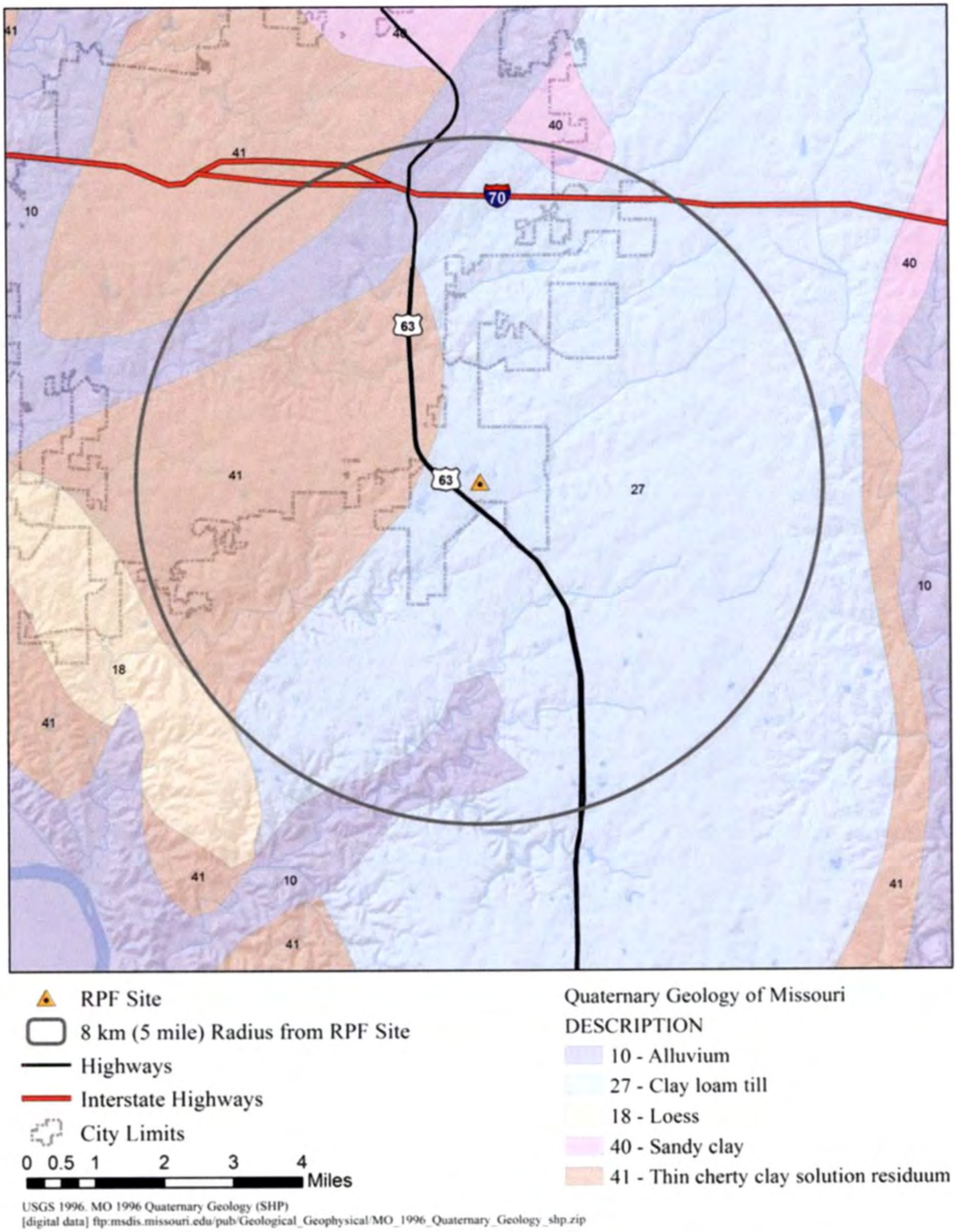

Figure 2-38. Map of Missouri Quaternary Age Geology

2.5.2.2 Pennsylvanian Age Desmoinesian Series Marmaton Group (Pm) and Cherokee Group (Pc)

Pennsylvanian age strata (both Marmaton and Cherokee Groups) consists largely of clay and shale, with minor accounts of coal and thin, impure limestone beds. The total thickness may be as much as 33.5 m (110 ft). These beds produce only small quantities of water and are not used in this area as a source of supply. The water found in this unit is usually high in iron and sulfur content (MU, 2006).

Limestone and shale beds are generally thin and very widespread lateral units. Pennsylvanian deposits are quite extensive across Missouri, and they usually form thin- to medium-bedded layers of distinctive composition, called cyclothems. A cyclothem results when a sea transgresses and regresses very rapidly along a coastal area, and in a repeating pattern. Often, this pattern consists of a sandstone (beach), silty shale or siltstone (tidal), freshwater limestone (lagoon), underclay (terrestrial), coal (terrestrial swampy forest), shale (near shore tidal), limestone (shallow marine), and black shale (deep marine). This sequence can then repeat itself as the sea first regresses from the land, and then transgresses again (MDNR, 2013c).

2.5.2.3 Mississippian Age Osagean Series Burlington Formation (Mo)

The Mississippian age Burlington Formation stratum is the most extensively studied Mississippian age strata in Missouri. This crystalline, extremely fossiliferous limestone covers most of the state and extends into Iowa and Arkansas. Typical characteristics include white-to-gray, medium-to-coarsely grained layers of chert nodules, and a coarse-grained sedimentary structure called "styolites" formed from pressure solution. The pores in the styolites are often filled with chert or quartz deposits (MDNR, 2013d).

Burlington limestone is the principal limestone exposed in quarries, creek banks, and roadcuts near and around Columbia. This limestone is approximately 49 m (160 ft) thick in the Columbia area (but the thickness can vary) and may contain minor amounts of pyrite and limonite. Burlington limestone has historically been economically important as a limestone resource where exposed and as host rock for lead and zinc deposits in the presently inactive Tri-State mining district of Missouri, Kansas, and Oklahoma (MU, 2006).

Burlington limestone contains many shallow-drilled wells and yields sufficient quantities of relatively hard water for rural domestic supplies. The limestone is quite soluble and contains many caverns and solutions passages. Solution features, including caves and sinkholes, are commonly present in this formation (MU, 2006). Terracon Consultants, Inc. (Terracon) reported the following:

> *No caves or sinkholes are known to exist, or are published to exist within approximately 1 mi of the Discovery Ridge Research Park. However, several areas of known karst activity are present west and southwest of this project area and are in various stages of development. Site grading and drainage may alter site conditions and could possibly cause sinkholes in areas that have no history of this activity.* (Terracon, 2011)

No sinkholes have occurred at the RPF site since the Terracon preliminary report was issued in 2011. The most recent study (Boone County, 2015) shows that the project site is northeast of the nearest areas considered to have the potential for sinkholes. The most recent sinkhole occurred in May 2014 and was located on East Gans Creek Road, approximately 1.17 km (0.73 mi) to the southwest of the RPF site.

A site-specific geotechnical investigation of the RPF site will be conducted to ensure that the area does not have the potential for sinkholes. If the investigation does identify the potential for sinkholes, the RPF final design would incorporate one of the following alternatives: (1) excavate site both vertically and horizontally to remove that potential and backfill with structural fill, or (2) install piers to bedrock to support the substructure if a sinkhole was to occur.

If one of these alternatives needs to be implemented, the approach will be determined after the geotechnical investigation is complete, incorporated in the final RPF design, and included in the Operating License Application.

2.5.2.4 Mississippian Age Kinderhookian Series Chouteau Limestone (Mk)

The Mississippian age Chouteau Limestone stratum is a very fine-grained carbonate and, for the most part, is an evenly bedded bluish gray limestone. The upper part is somewhat massive and high in magnesium. Chouteau limestone is relatively impermeable due to its fine texture, restricting the movement of water to joints and small fissures. This unit is a poor source of water but yields small quantities to a few wells (MU, 2006).

2.5.2.5 Late to Early Devonian Limestone (D)

Devonian limestone strata deposits greatly vary in lithology, and range from very fine-grained to coarsely textured beds. Some of the beds are slightly sandy. In some areas of Columbia, Missouri, the Devonian limestone beds are approximately 9 m (30 ft) thick; in other well locations, this limestone bed is completely absent. Devonian limestone is not a valuable water producer (MU, 2006).

2.5.2.6 Early Ordovician Age Ibexian Series Dolomites (Ojc)

Ordovician age deposits found in the Columbia area include the following, from youngest to oldest (MU, 2006):

- **St. Peter Sandstone** – This formation, which is a very important aquifer in eastern and northern Missouri, has no importance in the Columbia area. It is present only as localized masses in the depressions of older rocks.
- **Jefferson City Formation** – This predominantly dolomite formation averages approximately 122 m (400 ft) in thickness in the Columbia area, and wells drilled into it produce moderate quantities of relatively hard water. The formation probably has more rural domestic wells terminating in it than any other formation is this area.
- **Roubidoux Formation** – This formation consists of alternating sandstone and dolomite beds and averages approximately 30.5 m (100 ft) in thickness. The formation is a very dependable water producer.
- **Gasconade Formation** – This unit consists of mostly light-gray dolomite with sandstone (Gunter) at the base. The thickness is approximately 85.3 m (280 ft). This dolomite unit is very cavernous and contains many interconnected solution passages. The sandstone is approximately 4.6 m (15 ft) thick, is very permeable, has a wide aerial extent, and is a good source of water.

2.5.3 On-site Soil Types

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) Soil Survey Geographic database for Boone County (NRCS, 2012) lists the soil type beneath the proposed RPF site as the Mexico Silt Loam.

In 2011, Terracon completed a preliminary geotechnical investigation for the Discovery Ridge Certified Site Program, which included Lot 2 and Lots 5 through 18 of Discovery Ridge (Terracon, 2011). The proposed RPF site (Lot 15) is within the investigation area. The purpose of the investigation was to provide preliminary geotechnical recommendations concerning earthwork and the design and construction of foundations, floor slabs, and pavements for Discovery Ridge properties.

As part of the study, nine soil borings (B-1 through B-9) were installed to depths ranging from 4–6 m (13–20 ft) below-ground surface to determine shallow subsurface soil geotechnical properties and shallow groundwater depth. Soil boring B-5 is nearest to the proposed RPF site, along the eastern boundary between Lots 14 and 15.

Discovery Ridge surface soils from 0.6–0.15 m (0.2–0.5 ft) below-ground surface were found to be brown, friable topsoil with significant amounts of organic matter. Subsurface soils from approximately 0.9–3.6 m (3–12 ft) below-ground surface were lean clay, lean-to-fat clay, and fat clay with moderate-to-high plasticity. Material beneath 3.6 m (12 ft) is listed only as limestone. Plasticity and liquid limit tests were completed for soils encountered from only four soil borings.

At the time of drilling, some of the soils displayed moisture levels greater their measured plastic limits. "Soils with moisture levels above their measured plastic limits may be prone to rutting and can develop unstable subgrade conditions during general construction operations" (Terracon, 2011). Moderate to high plasticity clays were observed at the site. Such soils are commonly referred to as "expansive" or "swelling" soils because they expand or swell as their moisture content increases. These soils in turn, contract or shrink as the moisture content decreases. Footings, floor slabs, and pavements supported on expansive soils often shift upward or downward causing possible distortion, cracking, or structural damage.

A site-specific geotechnical investigation of the RPF site will be conducted to identify the site-specific soil characteristics. I f highly plastic clays are identified at the site, the design will include excavation of the clays and then backfill with structural fill. The structural details will be developed in the final RPF design and included in the Operating License Application.

2.5.4 Seismicity

The most significant seismological feature in Missouri is the New Madrid Seismic Zone (NMSZ), located in the southeastern corner of the state and extending into parts of the contiguous states of Arkansas, Tennessee, Kentucky, and Illinois. The NMSZ is the most seismically active region in the U.S. east of the Rocky Mountains and is located approximately 483 km (300 mi) southeast of the proposed RPF site. During the winter of 1811–1812, the NMSZ was the location of some of the highest intensity seismic events ever noted in U.S. history. Hundreds of aftershocks, some severely damaging, continued for years.

Records show that since 1900, moderately damaging earthquakes have struck the NMSZ every few decades. Prehistoric earthquakes similar in size to those of 1811–1812 occurred in the middle 1400s and around 900 A.D. Strongly damaging earthquakes struck the southwestern end of the NMSZ near Marked Tree, Arkansas, in 1843 (magnitude 6.0), and the northeastern end near Charleston, Missouri, in 1895 (magnitude 6.6) (USGS, 2011a).

The NMSZ is made up of reactivated faults that formed when what is now North America began to split or rift apart approximately 500 million years ago. The resulting rift system died out before an ocean basin was formed, but a deep zone of weakness was created, referred to as the Reelfoot rift (USGS, 2011b). This fault system extends 241 km (150 mi) southward from Cairo, Illinois, through New Madrid and Caruthersville, Missouri, down through Blytheville, Arkansas, to Marked Tree, Arkansas. The Reelfoot rift dips into Kentucky near Fulton and into Tennessee near Reelfoot Lake, extending southeast into Dyersburg, Tennessee. The rift then crosses five state lines and crosses the Mississippi River in at least three places. The fault system is buried beneath as much as 8 km (5 mi) of sediment for much of the fault length and typically cannot be seen at the surface (USGS, 2011b).

Four of the largest faults are recognized as alignments of abundant small earthquakes, and movements along two of these faults dammed rivers and created lakes during the earthquakes of 1811–1812. A few more deeply buried faults were detected during oil and gas exploration, and a few small faults are known from geologic mapping (USGS, 2011b).

The remainder of the state, including the proposed RPF site located in central Missouri, is typical of the stable midcontinent U.S.

Earthquakes occur on faults within bedrock, usually several miles deep. According to the U.S. Geological Survey (USGS), earthquakes in the central and eastern U.S. typically are felt over a much broader region than in the western U.S. East of the Rocky Mountains, an earthquake can be felt over an area ten times larger than a similar magnitude earthquake on the west coast.

According to information from Missouri's State Emergency Management Agency Earthquake Program, some of the earthquakes measure at least 7.6 in magnitude and five of them measured 8.0 or greater. The 1811–1812 series changed the course of the Missouri River, and some shocks were felt as far away as Washington D.C. and Boston (MMRPC, 2010). The NMSZ has experienced numerous earthquakes since the 1811–1812 series, and at least 35 aftershocks of intensity V or greater that have been recorded in the Missouri since 1811. Numerous earthquakes originating outside of the state's boundaries have also affected Missouri. Table 2-41 summarizes the historical earthquakes that have affected the state of Missouri.

Table 2-41. Recorded Missouri Earthquake History (4 pages)

Date	Location	Magnitude	Recorded damage
12/16/1811 (1811–1812 series)	New Madrid Region, Missouri	7.7	Generated great waves on the Mississippi River causing major flooding, high river back cave-ins. Topographic changes affected an area of 78,000 to 130,000 km^2 (30,116 to 50,193 mi^2). Later geologic evidence indicated that the epicenter was likely in northeast Arkansas. The main shocks were felt over an area covering at least 5,180,000 km^2 (2,000,000 mi^2). Chimneys were knocked down in Cincinnati, Ohio, and bricks were reported to have fallen from chimneys in Georgia and South Carolina. The first shock was felt distinctively in Washington, D.C., 1,127 km (700 mi) away.
12/23/1812 (1811–1812 series)	New Madrid, Missouri	7.5	Second major shock more violent than the first.
2/7/1812 (1811–1812 series)	New Madrid, Missouri	7.7	Three main shocks reaching MMI of XII, the maximum on scale. Aftershocks continued to be felt for several years after the initial tremor. Historical accounts and later evidence indicate that the epicenter was close to the town of New Madrid, Missouri. This quake produced the largest liquefactions fields in the world.
1/4/1843	New Madrid, Missouri	Not listed	Cracked chimneys and walls in Memphis, Tennessee, and reportedly collapsed one building. The earth sank in some places near the town of New Madrid, Missouri, and an unverified report indicated that two hunters were drowned during the formation of a lake. The total felt area included at least 1,036,000 km^2 (400,000 mi^2).

Table 2-41. Recorded Missouri Earthquake History (4 pages)

Date	Location	Magnitude	Recorded damage
4/24/1867	Eastern Kansas	Not listed	Reports indicated that an earthquake occurred in eastern Kansas and was felt as far eastward as Chicago, Illinois. It may have been noticeable in Columbia.
8/31/1886	Charleston, South Carolina	Not listed	An MMI of II earthquake recorded in St. Louis, Missouri, and was felt as far westward as Columbia. There were no reports of structural damage.
10/31/1895	Charleston, Missouri	6.6	Largest earthquake to occur in the central Mississippi River valley since the 1811–1812 series. Structural damage and liquefaction phenomena were reported along a line from Bertrand, Missouri, in the west to Cairo, Illinois, to the east. Sand blows were observed in an area southwest of Charleston, Puxico, and Taylor, Missouri; Alton, and Cario, Illinois; Princeton, Indiana; and Paducah, Kentucky. The earthquake caused extensive damage (including downed chimneys, cracked walls, shattered windows, and broken plaster) to schools, churches, and private residences. Every building in the commercial area of Charleston was damaged. Cairo, Illinois, and Memphis, Tennessee, suffered significant damage. Near Charleston, 1.6 ha (4 acres) of ground sank and a lake formed. The shock was felt over all or portions of 24 states and in Canada. Ground shaking was recorded along the Ohio River Valley.
1903	New Madrid, Missouri	5.1	No information given.
4/9/1917	St. Genevieve/ St. Mary's Area, Missouri	Not listed	A sharp disturbance at St. Genevieve and St. Mary's, Missouri. According to the Daily Missourian, No. 187, dated April 9, 1917, the earthquake was not felt in Columbia. However, on the following day several people reported feeling the shock and attributed it to an explosion. No damage was reported in Columbia. Reportedly felt over a 518,000 km^2 (200,000 mi^2) area from Kansas to Ohio and Wisconsin to Mississippi.
5/1/1920	Missouri or Illinois	Not listed	This earthquake reportedly shook buildings across St. Louis. Two shocks were felt in Mt. Vernon, Illinois, and three were felt in Centralia, Illinois. The epicenter of this earthquake is unknown and is thought to have originated east of Columbia in Illinois. In the Evening Missourian, No. 207, dated May 1, 1920, the U.S. Weather Bureau reported that the shock was not felt in Columbia. However, in a later investigation a few people reported feeling a slight tremor.

Table 2-41. Recorded Missouri Earthquake History (4 pages)

Date	Location	Magnitude	Recorded damage
8/19/1934	Rodney, Missouri	Listed as strong	At nearby Charleston, windows were broken and chimneys collapsed or were damaged. Similar effects were observed in Cairo, Mounds, and Mounds City, Illinois, and at Wickliffe, Kentucky. The area of destructive intensity included more than 596 km^2 (230 mi^2)
11/23/1939	Western Illinois	Not listed	An earthquake occurred near Red Bud, Illinois, and a reported MMI of II was recorded in Columbia, Missouri. The approximately distance from the epicenter to Columbia was 213 km (132 mi).
3/3/1963	Near Menorkanut, Missouri	Not listed	MMI of III was recorded in Columbia. The approximately distance from the epicenter to Columbia was 317 km (197 mi).
10/21/1965	Eastern Missouri	Not listed	MMI of V in Columbia. The approximate distance from the epicenter to Columbia was 163 km) (101 mi).
11/9/1968	Wabash Valley Seismic Zone, southern Illinois	5.4	Strongest magnitude in central U.S. since the 1895 earthquake. Moderate damage to chimneys and walls at Hermann, St. Charles, St. Louis, and Sikeston, Missouri. Shaking was felt. Areas include all or portions of 23 states from Minnesota to Georgia and from Pennsylvania to Kansas, and in multi-story buildings in Boston, Massachusetts and southernmost Ontario, Canada.
1987	Wabash Valley Seismic Zone, near Olney, Richland County, SE Illinois	5.0	Chimneys and bricks fell, underground pipes were damaged, and sidewalks and streets cracked in at least four cities in Illinois, Indiana, and Kentucky. Shaking was felt in 17 states, from Pennsylvania to Kansas and from Alabama to Minnesota and southernmost Ontario, Canada.
2002	Wabash Valley Seismic Zone, Posey County, SW Indiana	4.6	Moderate earthquake caused chimney damage and cracked windows in and near Evansville, Indiana. Shaking was reported in seven states, including Missouri.
8/16/2003	20 km WNW of Alton, Missouri	3.7	Minor quake, no damage reported
5/18/2005	Missouri	3.3	Minor quake, no damage reported
7/31/2005	Missouri	3.3	Minor quake, no damage reported
6/7/2011	18 km NNW of Potosi, Missouri	3.9	Minor quake, no damage reported
9/22/2011	22 km NNE of Doniphan, Missouri	3.6	Minor quake, no damage reported

Table 2-41. Recorded Missouri Earthquake History (4 pages)

Date	Location	Magnitude	Recorded damage
1/16/2015	15 km N of Doniphan, Missouri	3.5	Minor quake, no damage reported
10/16/2015	14 km NNW of Doniphan, Missouri	3.2	Minor quake, no damage reported
7/5/2016	6 km SW of Caruthersville, Missouri	3.0	Minor quake, no damage reported

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MMI = Modified Mercalli Intensity.

2.5.5 Maximum Earthquake Potential

In 2002, the USGS released the following projected hazards for Boone County, if an earthquake occurred along the NMSZ in the following 50 years (MMRPC, 2012):

- 25 to 40 percent chance of a magnitude 6.0 and greater earthquake
- 7 to 10 percent chance of a magnitude 7.5 to 8.0 earthquake.

According to the USGS, Boone County is one of the 47 counties in Missouri that would be severely impacted by a 7.6 magnitude earthquake with an epicenter on or near the NMSZ.

According to the *Boone County Hazard Mitigation Plan for 2010* (MMRPC, 2010), the Missouri State Emergency Management Agency has made projections of the highest earthquake intensities that would be experienced throughout the state of Missouri if various magnitude earthquakes occur along the NMSZ (Figure 2-39, on the next page), as measured by the Modified Mercalli Intensity (MMI) scale. The pertinent information for Boone County is summarized in Table 2-42.

Table 2-42. Projected Earthquake Hazards for Boone County

Magnitude at NMSZ	Probability of occurrence (2002–2052)	Intensity in Boone County (MMI)	Expected damage
6.7	25–40%	VI, strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
7.6	7–10%	VII, very strong	Difficult to stand; significant damage to poorly or badly designed buildings, adobe houses, old walls, spires, and other; damage would be slight to moderate in well-built buildings; numerous broken windows; weak chimneys break at roof lines; cornices from towers and high buildings fall; loose bricks fall from buildings; heavy furniture is overturned and damaged; and some sand and gravel streambanks cave in.

Source: MMRPC, 2010, *Boone County Hazard Mitigation Plan*, www.mmrpc.org/the-region/boone-county, Mid-Missouri Regional Planning Commission, State of Missouri Emergency Management Agency, Ashland, Missouri, July 15, 2010.

MMI = Modified Mercalli Intensity. NMSZ = New Madrid Seismic Zone.

The USGS National Seismic Hazard Maps display earthquake ground motions for various probability levels across the U.S. and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy. Updates to these maps incorporate new findings on earthquake ground shaking, faults, seismicity, and geodesy. The resulting maps are derived from seismic hazard curves calculated on a grid of sites across the U.S. that describe the frequency of exceeding a set of ground motions. In accordance with the 2008 USGS Scientific Investigation Map (No. 3195) (USGS, 2008), the proposed RPF site is within the third lowest earthquake hazard area with peak acceleration potentials of 2–3 (Petersen et al., 2011). This category indicates an estimated horizontal ground-shaking level between 8-in-100 to 16-in-100 chance of being exceeded in a 50-year period.

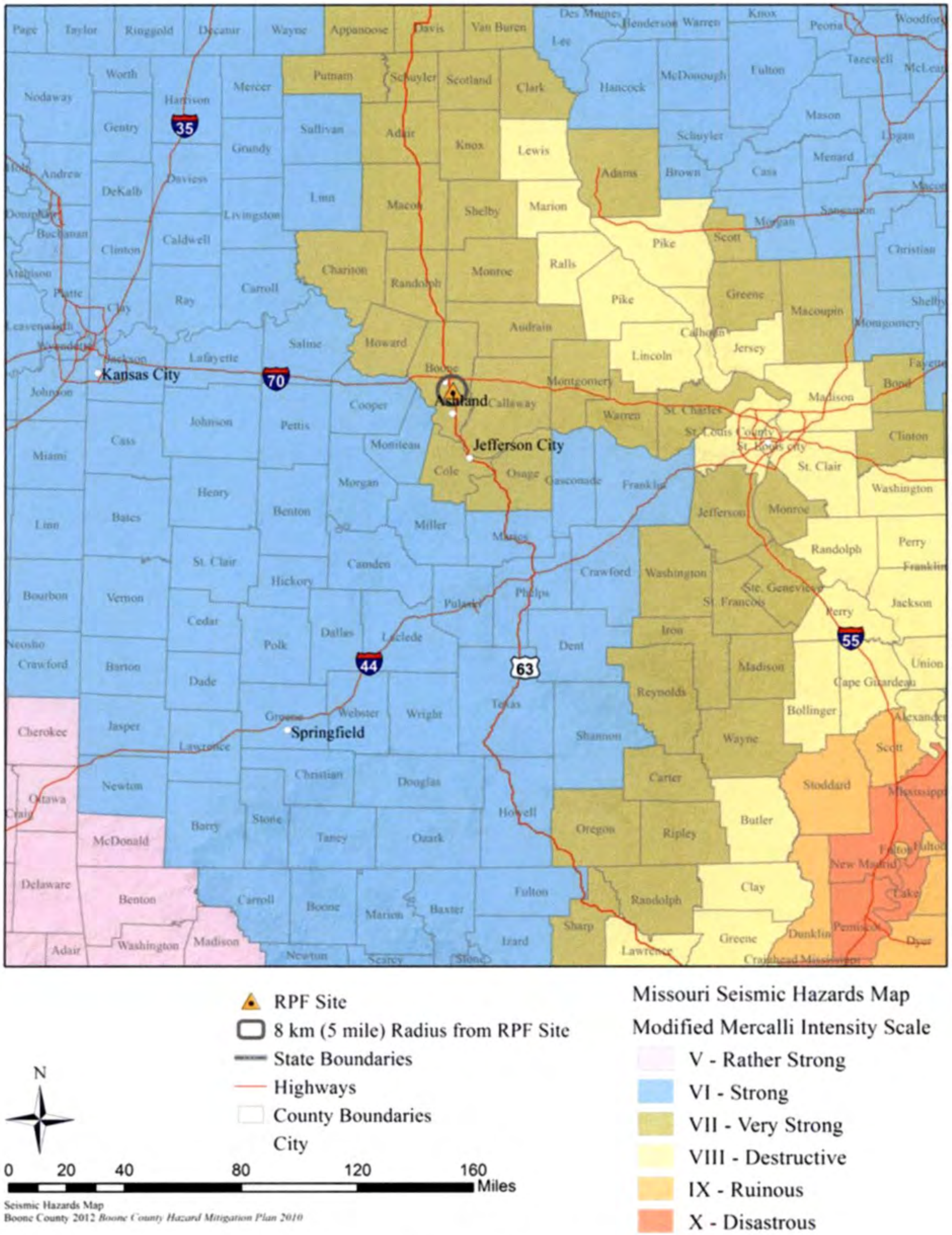

Figure 2-39. Hazard Mitigation Map

According to MMRPC (2010), the entire county is at risk for effects of an earthquake along the NMSZ. Areas near the Missouri River could be particularly vulnerable due to the soil or alluvium along river channels being susceptible to liquefaction from amplification waves.

2.5.6 Vibratory Ground Motion

NUREG-1537, Part 1, Section 3.4 requires that seismic design for non-power reactors should, at a minimum, be consistent with local building codes and other applicable standards. For MU facilities, the 2012 IBC has been levied as the required building code. Therefore, seismic design parameters for the proposed project are discussed in terms of the 2012 IBC and associated standards.

Seismic provisions in 2012 IBC, Chapter 16, Section 13, "Earthquake Loads," and ASCE 7-10, Chapter 11, are based on 5 percent damped spectral accelerations for a maximum-considered earthquake with a return period of 2,475 years (equivalent to a ground motion with a 2 percent probability of exceedance in 50 years). Spectral acceleration values for the maximum considered earthquake are for soil Site Class B (rock). The short- (S_S) and long- (S_1) period spectral accelerations for rock sites are provided by Boone County and are based on USGS (2009) data.

In the 2012 IBC, Site Class B soil conditions require modification for other soil site classes by the application of the site coefficients F_a (site coefficient for 0.2-sec period) and F_v (site coefficient for 1-sec period). Soil-modified S_S becomes S_{MS} (maximum-considered earthquake spectral response for 0.2 sec modified for soil Site Class) and soil-modified S_1 become S_{M1} (maximum-considered earthquake spectral response for 1-sec period modified for soil Site Class) where $S_{MS} = S_S \times F_a$ and $S_{M1} = S_1 \times F_v$ (Equations 16-36 and 16-37 in IBC, 2012). Boone County, Missouri indicates S_S and S1 values of 0.213 g-force (g) and 0.093 g, respectively (Fa and $F_v = 1$) for the site.

The Boone County site is classified as soil Site Class C, which is defined as soils predominately of very dense glacial tills, sands, and gravels, and soil sites with very shallow rock often qualify.

NWMI has committed to using the NRC Regulatory Guide 1.60, *Design Response Spectra for Seismic Design of Nuclear Power* Plants, for the final seismic design. The estimated maximum ground acceleration at the RPF site will meet Regulatory Guide 1.60 free-field response spectrum anchored to a peak ground acceleration of 0.20 g. The Regulatory Guide 1.60 spectrum eliminates the need for soil classifications used as part of the IBC methodology.

In addition, Chapter 3.0, Sections 3.4 and 3.5 provide design criteria and the analysis methodology for seismic events, including a safe shutdown earthquake. The seismic design of the RPF and associated items relied on for safety (IROFS) will ensure the functionality and/or integrity of structures, systems, and components required to prevent radiological release below the performance requirements of 10 CFR 70.61. Additional information on the seismic requirements and evaluations of the RPF and associated IROFS will be provided in the Operating License Application.

2.5.7 Surface Faulting

There is one major fault zone located within a five-mile radius of the proposed RPF site (Figure 2-40). The Fox Hallow Fault is located approximately 5.6 km (3.5 mi) southeast of the proposed RPF site. The Fox Hollow Fault is a small fault, striking northeast, and fades into a monocline at its two ends. The fault is reportedly a normal fault with a throw of approximately 37 m (120 ft) down to the southwest, and shows Mississippian-aged Chouteau limestone beds faulted against Ordovician-aged Jefferson Dolomite (Union Electric Company, 2008).

During the Union Electric Company study, the Fox Hollow fault was investigated at six waypoints where visual observations of the fault were made. These, plus other road cuts in the local area, were investigated for evidence of offsets and shears. No new roads have been cut or significant new development has occurred recently in the area.

At Waypoint 1, which is in Fox Hollow where the valley runs normal to the Fox Hollow Fault, the valley is heavily vegetated and reworked for agriculture. An outcrop of Jefferson Dolomite, about 91 m (300 ft) long, was observed on the north side of the valley. The Jefferson is dipping about 5 degrees to the west on the west flank or down-dipping of a monocline.

At the other waypoints along the fault alignment, the vegetation was heavy and the ground surface had been reworked for agriculture. No evidence of the fault was observed in any road cuts in the area, and no surface manifestation of the fault was observed at any of the waypoints.

The field investigation was expanded to the east of the fault along State Highway 63, which runs sub-parallel to the main feature and reportedly on the up-thrown side. Depending on the location, State Highway 63 runs about 4.8 to 5.6 km (3 to 3.5 mi) to the east of the feature. All road cuts along State Highway 63, and the east-west roads running from the fault to State Highway 63, were examined for offsets, abrupt changes in dip, and evidence of shearing. In each case, questionable features were linked to non-tectonic causes, primarily erosion or slumping associated with the road itself. Based on the Union Electric Company investigation, the fault was inactive at the time of their study.

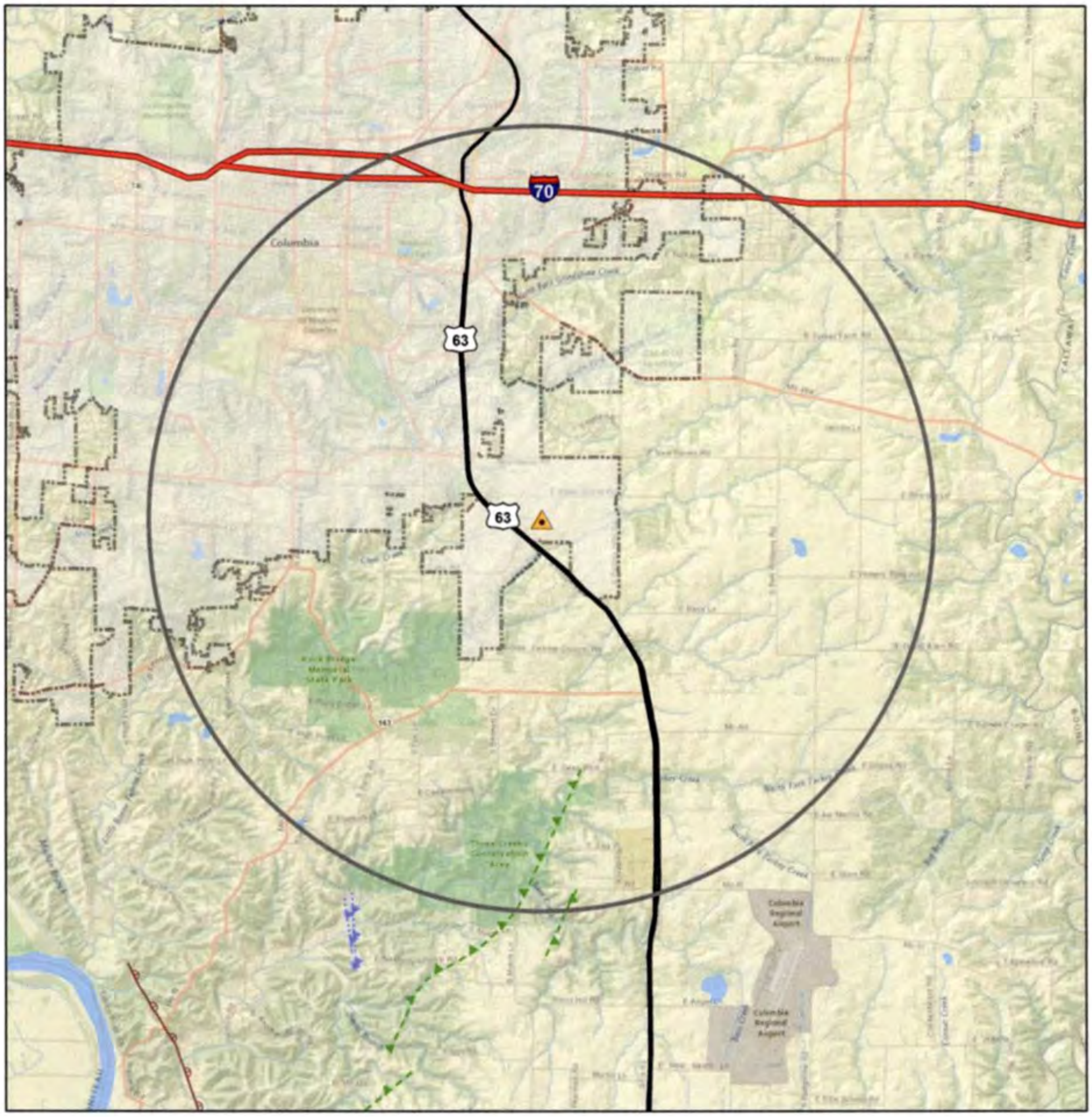

Figure 2-40. Geologic Faults Map

2.5.8 Liquefaction Potential

Liquefaction is a process by which water-saturated sediment temporarily loses strength and acts as a fluid when exposed to strong seismic shaking. The shaking causes the grains to lose grain-to-grain contact, so the sediment tends to flow. Liquefaction most likely occurs in loose sandy soil with a shallow water table (which is common for areas around floodplains or bays). Liquefaction often leads to overpressured fluids that can erupt to the surface, forming features known as sand blows.

The 1811–1812 earthquakes caused ground subsidence by soil liquefaction across the Mississippi River flood plain and along tributaries to the Mississippi River over at least 15,000 km^2. Liquefaction along the Mississippi River Valley during the 1811-1812 earthquakes created one of the world's largest sand blown fields. According to the USGS, recent sand blows dot the landscape surrounding New Madrid, Missouri (USGS, 2011b).

The Association of Central United States Earthquake Consortium State Geologists (CUSEC) established regional maps identifying areas of higher and lower potential for amplification of earthquake ground motion by soils or liquefaction of the soils. The areas were defined on the basis of the geology of the upper 15 m (50 ft). Their map identifies the RPF area as an area of having lower potential for amplifying earthquake ground motions or liquefaction (CUSEC, 1999).

The Terracon (2011) preliminary geotechnical investigation for the Discovery Ridge Certified Site Program included Lot 2 and Lots 5 through 18 of the Discovery Ridge Research Park. The proposed RPF site (Lot 15) is located within Terracon's project area. As part of their study, Terracon installed nine soil borings (B-1 through B-9) to depths ranging from 4 to 6 m (13 to 20 ft) below-ground surface. Soil boring B-5 was drilled nearest to the proposed RPF site and was installed along the eastern boundary between Lots 14 and 15.

Soils – Terracon described the subsurface soils in soil boring B-5 as listed below:

- 6-9.1 cm (0.2-0.3 ft) below-ground surface; brown, friable topsoil with significant amounts of organic matter
- 9.1-91 cm (0.3-3.0 ft) below-ground surface; lean clay (CL), brown, stiff, water content 24 percent, dry unit weight 98 lb/ft^3, and unconfined strength 4,000 kilopounds per square foot (kip/ft^2)
- 0.9-2.4 m (3.0-8.0 ft) below-ground surface; fat clay (CH), gray with red, stiff, water content 31 percent, dry unit weight 91 lb/ft^3, and unconfined strength 4,000 kip/ft^2
- 2.4-3.7 m (8.0-12.0 ft) below-ground surface; fat clay (CH), reddish brown and light gray, trace sand and gravel, possible cobbles, stiff (glacial drift), water content 16 percent, dry unit weight 116 lb/ft^3, and unconfined strength 7,000 kip/ft^2
- 3.7-5.2 m (12.0-17 ft) below-ground surface; sandy lean to fat clay (CL-CH), reddish brown with light gray, trace gravel, possible cobbles, stiff (glacial drift), water content 21 percent, and unconfined strength 4,000 kip/ft^2.
- 5.2-6.1 m (17-20 ft) below-ground surface; fat clay (CH), reddish brown and light gray, trace sand and gravel, possible cobbles, very stiff (glacial drift), standard penetration test blow count = 19, water content 18 percent, and unconfined strength 7,500 kip/ft^2.

Laboratory testing indicated that the lean clay tested from soil boring B-5, 0.3-0.91 m (1-3 ft) below-ground surface, had a liquid limit of 31 percent, a plastic limit of 21 percent, and a plasticity index of 10 percent.

Groundwater level – Shallow groundwater encountered at the time of drilling in soil boring B-5 was at 5 m (16.5 ft) below-ground surface and the static water level stabilized at 3.7 m (12.0 ft) below-ground surface. Shallow groundwater was not encountered in soil boring B-6 (located on Lot 10) during the drilling operation, but later stabilized at 5.6 m (18.5 ft) below-ground surface.

Liquefaction potential – Based on the preliminary geotechnical study conducted by Terracon (2011), liquefaction of soils at the proposed RPF site cannot be determined. Contradictory information is listed below:

- In accordance with liquefaction potential screening techniques, cohesive soils with fines content greater than 30 percent and fines that are either classified as clays based on the Unified Soil Classification System or have a plasticity index greater than 30 percent with natural water contents lower than 90 percent, can be considered nonliquefiable. Soils logged in soil boring B-5 are listed as clays under the Unified Soil Classification System; however, the plasticity index is only 10 percent, with water contents ranging from 16 to 31 percent.
- Depth below-ground surface – A soil layer within 50 ft of the ground surface is more likely to liquefy than deeper layers.
- Soil penetration resistance – Soil layers with a normalized standard penetration test blow count less than 22 have been known to liquefy. The standard penetration test blow count listed for soil boring B-5 is 19. In accordance with the statement above, this would depict soils susceptible to liquefaction.

Additional geotechnical analysis will be conducted at the RPF site to determine the liquefaction potential of the soils onsite and included in the Operating License Application.

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