CHAPTER 1

THE FACILITY

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition
°C	degrees Celsius
°F	degrees Fahrenheit
10 CFR	Title 10 of the Code of Federal Regulations
ac.	acre
AHA	acetohydroxamic acid
ALARA	as low as reasonably achievable
ANSI/ANS	American National Standards Institute/ American Nuclear Society
CAAS	criticality accident and alarm system
CAMS	continuous air monitoring system
CFR	Code of Federal Regulations
CP	Construction Permit
DBA	design basis accident
DOE	U.S. Department of Energy
ESF	engineered safety feature
ESFAS	engineered safety feature actuation system
gal.	gallon
GNEP	Global Nuclear Energy Partnership
ha	hectare
HAZOPS	hazards and operability study
HEU	highly enriched uranium
IE	initiating event
IF	irradiation facility
INL	Idaho National Engineering Laboratory
ISA	integrated safety analysis

Acronyms and Abbreviations (cont'd)

Acronym/Abbreviation	Definition
ISG	Interim Staff Guidance
IU	irradiation unit
km	kilometer
L	liter
LEU	low enriched uranium
LWPS	light water pool system
MEPS	mo extraction and purification system
MeV	million electron volt
MHA	maximum hypothetical accident
mi.	miles
MIPS	moly isotope product packaging system
Mo	molybdenum
Mo-99	molybdenum-99
MUPS	light water pool and primary closed loop cooling make-up system
NDAS	neutron driver assembly system
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PCLS	primary closed loop cooling system
PHA	preliminary hazard analysis
PSAR	Preliminary Safety Analysis Report
PSB	primary system boundary
PUREX	plutonium and uranium extraction
PVVS	process vessel vent system
RAMS	radiation area monitoring system
RCA	radiologically controlled area

Acronyms and Abbreviations (cont'd)

Acronym/Abbreviation	Definition
RDS	radioactive drain system
RICS	radiological integrated control system
RPCS	radioisotope process facility cooling system
RPF	radioisotope production facility
RV	radiologically controlled area (RCA) ventilation system
SASS	subcritical assembly support structure
SCAS	subcritical assembly system
SHINE	SHINE Medical Technologies, Inc.
SIXEP	site ion exchange effluent plant
SNM	special nuclear material
SRWP	solid radioactive waste packaging system
SSC	structure, system, and component
TBP	tributyl phosphate
Tc-99m	technetium-99m
TPS	tritium purification system
TOGS	TSV off-gas system
TPCS	TSV process control system
TRPS	TSV reactivity protection system
TSPS	target solution preparation system
TSV	target solution vessel
U-235	uranium-235
UNCS	uranyl nitrate conversion system
UPSS	uninterruptible electrical power supply system
UREX	uranium extraction
VDC	volts-direct current

CHAPTER 1

THE FACILITY

1.1 INTRODUCTION

This Preliminary Safety Analysis Report (PSAR) is submitted in accordance with the provisions of Title 10 of the Code of Federal Regulations (10 CFR) Part 50 “Domestic Licensing of Production and Utilization Facilities,” in support of the application by SHINE Medical Technologies, Inc. (SHINE) to construct a medical isotope production facility.

This PSAR generally follows the content and organization of NUREG-1537, Part 1, Guidelines for Preparing and Reviewing Applications for the Licensing of Non Power Reactors, Format and Content, as augmented by the Final Interim Staff Guidance (ISG) Augmenting NUREG-1537, Part 1, Guidelines for Preparing and Reviewing Applications for Licensing Non-Power Reactors: Format and Content for Licensing Radioisotope Production Facilities and Aqueous Homogeneous Reactors, October 17, 2012.

The applicant for this Construction Permit (CP) and owner of the medical isotope production facility is SHINE Medical Technologies, Inc., a Wisconsin corporation. SHINE is a private organization that was created for the purpose of designing, constructing, and operating the facility described herein. The purpose of the facility is to produce molybdenum-99 (Mo-99). Additional information about the SHINE organization and key personnel is provided in Section 12.1.

The facility is located on previously-undeveloped property in the City of Janesville, Rock County, Wisconsin. The SHINE site and details regarding the geographical location and the surrounding areas are presented in Chapter 2.

SHINE has developed a new method for the manufacture of medical isotopes, primarily Mo-99. Mo-99 is the precursor of the diagnostic imaging isotope, technetium-99m (Tc-99m), which is used in over 30 different diagnostic imaging procedures and in 80 percent of nuclear diagnostic procedures worldwide. Technetium becomes a “light source” within the body to provide a high quality view of internal organs. It is primarily used in cancer screening and in stress tests to detect heart disease. Approximately 55,000 medical imaging procedures are performed daily in the U.S., and approximately an equal number are performed internationally.

SHINE’s technology involves the use of a non-reactor based, subcritical fission process. The process includes the combination of a high-output deuterium-tritium gas-target neutron source with a low enriched uranium (LEU) target in a target solution vessel (TSV). Neutrons created by simple, accelerator-driven neutron sources induce fission in the LEU, creating Mo-99 as a byproduct. The combination of the neutron driver, subcritical assembly, light water pool, TSV off-gas system (TOGS), and other supporting systems are known as the irradiation unit (IU). Eight IUs and their supporting systems comprise the irradiation facility (IF).

The SHINE facility also includes the radioisotope production facility (RPF). The RPF is where the irradiated material is processed to separate medical isotopes, and includes packaging of the resulting materials for shipment to customers. Detailed descriptions of the IF and the RPF are provided in Chapter 4.

Inherent and passive safety features of the facility are addressed in Subsection 1.2.3.

1.2 SUMMARY AND CONCLUSIONS ON PRINCIPAL SAFETY CONSIDERATIONS

This section identifies safety criteria, principal safety considerations and conclusions for the SHINE facility structures, systems, and components (SSCs).

1.2.1 CONSEQUENCES FROM THE OPERATION AND USE OF THE FACILITY

The primary consequences resulting from the operation of the SHINE facility are radiological. The SHINE facility produces Mo-99 from irradiation of LEU. The LEU is in the form of a uranyl sulfate target solution. In the IUs, the target solution is irradiated in a subcritical assembly by neutrons produced by a fusion neutron source. The irradiated target solution is then processed in the RPF to extract and purify the Mo-99. Radioactive waste materials are processed and/or converted to solid wastes for shipment to off-site disposal facilities. The SHINE facility is designed to be a zero radioactive liquid effluent discharge facility.

The entire IF and RPF constitute the radiologically controlled area (RCA) (see Figure 1.3-5). Radioactive materials are present in the following major locations within the SHINE facility buildings:

- Production facility - IF
    - IU cells
    - TSV off-gas shielded cells
    - Tritium production areas
- Production facility - RPF
    - Target solution preparation and storage areas
    - Uranium extraction (UREX) hot cell and thermal denitration area
    - Extraction/purification/packaging hot cells (supercells)
    - Pump transfer cell
    - Waste processing hot cells
    - Noble gas storage cell
    - Labs and storage rooms
    - RCA ventilation equipment areas
- Production facility - other areas
    - Receiving area
    - Shipping area
- Waste staging and shipping building

As a result of working with radioactive materials, the staff receives occupational exposures, and members of the public 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 and 20.1301, 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 20.1301, respectively.

1.2.2 SAFETY CONSIDERATIONS

The reasons for selection of the specific site for the SHINE facility include:

- Local government and community support.
- Financial incentives.
- The size and shape of the proposed parcel.
- Access to a skilled workforce.
- Proximity to potential future customers.
- Proximity to an airport.
- Proximity to an interstate highway.
- Anticipated depth to ground water.
- Seismic characteristics.
- The presence of endangered resources and wetlands.
- The presence of historic and archeological resources.

Of these criteria, two are directly related to safety: the size and shape of the proposed parcel, and the seismic characteristics of the site. A greater distance from the facility to the site boundary decreases impacts on the public. Of the parcels considered, the Janesville site had the largest minimum distance to the site boundary. Given that there are no major fault lines in Wisconsin, the sites considered were all comparably attractive from a seismic safety perspective.

The medical isotopes are produced in a subcritical assembly. The subcritical assembly is different from a nuclear reactor because the subcritical assembly does not achieve criticality.

The subcritical assembly uses target solution consisting of LEU in the form of uranyl sulfate solution. The use of LEU as the source material meets U.S. government non-proliferation objectives related to elimination of the use of highly enriched uranium (HEU) for the production of medical isotopes.

Major processes performed at this facility that involve licensed quantities of radioactive material are discussed in Sections 1.3, 1.5, and 1.6.

1.2.3 INHERENT AND PASSIVE SAFETY FEATURES

1.2.3.1 Safety Features for the SSCs

The SHINE facility utilizes a number of inherent safety features that represent good engineering practice for nuclear processing facilities.

a. The RCA of the SHINE production facility is located within seismic Category I structures that are designed to survive the design basis earthquake and other design basis events. Inside the seismic Category I structures, other SSCs are supported in accordance with seismic Category II over seismic Category I criteria to prevent unacceptable interactions between non-seismic Category I SSCs and safety-related SSCs.
b. Tanks, equipment, and piping that are expected to contain significant quantities of fissile material are designed and/or controlled to be criticality-safe.
c. The design concept of confinement is utilized to prevent or minimize the spread of radioactive materials.

d. Shielding is used to minimize occupational exposures in normally-occupied areas of the facility from the radioactive materials contained within the process areas of the facility.
e. Ventilation systems for normally-occupied areas are separate from ventilation systems for areas containing radioactive materials. The ventilation system in the RCA is designed to pull air from the least contaminated areas to the most contaminated areas.
f. Areas, tanks, equipment, and piping that contain radioactive materials drain to criticality-safe sumps that are provided with leak detection to alert operators in the event of a breach of the primary fission product barrier or confinement areas.

1.2.3.2 Functional Safety Features

1.2.3.2.1 Radiological Safety

Shielding is used extensively to minimize personnel exposures. The IU cell walls are approximately six-foot thick reinforced concrete. This provides neutron and gamma shielding for workers above or adjacent to IU cells. The light water pool provides additional neutron and gamma shielding.

The concept of confinement is used in both the IF and the RPF to minimize the release and spread of contamination.

1.2.3.2.2 Criticality Safety

Criticality control is designed into the project by a combination of facility, systems, equipment, and processes. For operations outside the TSV, the facility is designed to meet the requirements of American National Standards Institute/American Nuclear Society (ANSI/ANS) 8.1 (ANS, 2007), including the double contingency principle. The hierarchy of controls is as follows:

a. The facility and equipment is designed so that significant quantities of fissionable material cannot be placed in a favorable configuration for criticality.
b. Engineered controls.
c. Administrative controls (e.g., limitations on allowed movements and processes involving special nuclear material [SNM]).

Fissile material is maintained in a shutdown state ($k_{eff} \leq 0.95$) in vessels and equipment in the facility except the TSV. The TSV is operated in a subcritical state.

1.2.4 DESIGN FEATURES AND DESIGN BASES

1.2.4.1 Design Bases for the SSCs

The SSCs at the SHINE facility are assigned a nuclear safety classification, as follows:

- Safety-related SSCs: Those SSCs that are relied upon to remain functional during normal conditions and during and following design basis events to assure:
  - The integrity of the primary system boundary (PSB);
  - The capability to shut down the TSV and maintain the target solution in a safe shut-down condition;

  - The capability to prevent or mitigate the consequences of accidents which could result in potential exposures comparable to the applicable guideline exposures set forth in 10 CFR 20;
  - That the potential for an inadvertent criticality accident is not credible;
  - That acute chemical exposures to an individual from licensed material or hazardous chemicals produced from licensed material could not lead to irreversible or other serious, long-lasting health effects to a worker or cause mild transient health effects to any individual located outside the owner controlled area; or
  - That an intake of 30 mg or greater of uranium in soluble form by any individual located outside the owner controlled area does not occur.

- Nonsafety-related: Those SSCs related to production and delivery of products or services that are not in the above safety classification.

The design bases and design for SHINE facility SSCs are addressed in Sections 3.1 and 3.5.

The SHINE production facility building is designed to withstand severe natural phenomena, including seismic events and tornado missiles. The building exterior wall structure is robust enough to remain intact following the impact of small aircraft, as defined in DOE (1996).

1.2.4.2 Functional Design Bases

1.2.4.2.1 Radiological Safety

A radiation protection program is provided to protect the radiological health and safety of workers and complies with the regulatory requirements in 10 CFR 19, 20, and 70. The Radiation Protection Program meets the requirements of 10 CFR 20, Subpart B, Radiation Protection Programs, and is consistent with the guidance provided in Regulatory Guide 8.2. This program is described in Subsection 11.1.2.

The radiation protection program includes an as low as reasonably achievable (ALARA) program. The facility's commitment to the implementation of an ALARA program is described in Subsection 11.1.3. The objective of the program is to make every reasonable effort to maintain personnel exposures to radiation as far below the dose limits of 10 CFR 20.1201 as is practical. The design and implementation of the ALARA program is consistent with the guidance provided in Regulatory Guides 8.2, 8.13, and 8.29. The operation of the SHINE facility is consistent with the guidance provided in Regulatory Guide 8.10.

Radiation monitoring and surveying are utilized to minimize the occupational dose to personnel. The program equipment and procedures are addressed in Subsection 11.1.4. This includes the use of area radiation monitors, continuous air monitors, the detection and monitoring of gaseous and liquid effluent release streams, control point monitoring, and the use of radiation surveys within the SHINE facility.

Occupational dose is also controlled and minimized through the use of dosimetry and exposure control. This includes the establishment of controlled areas within the facility, the use of access and egress controls, the use of protective clothing and equipment, the monitoring of personnel for exposures through the use of dosimetry and portal monitors, posting of facility areas, and personnel training. Subsection 11.1.5 describes these features and provisions.

Contamination controls are provided to prevent the spread of contamination within the facility and to the environment. Contamination control is described in Subsection 11.1.6.

Environmental monitoring is provided to verify that releases of radioactive materials are within regulatory limits. Subsection 11.1.7 describes monitoring of effluent release pathways, ingestion pathways, groundwater monitoring, and site surveys.

1.2.4.2.2 Criticality Safety

Criticality control is provided in the TSV through the following passive, active, and administrative controls.

Passive engineered controls:

a. Valve, pipe, and pump sizing limits the flow rate of solution from the target solution hold tank into the TSV.
b. The target solution hold tank is located below the TSV, requiring motive force to move the solution into the TSV.
c. The TSV dump tank is located below the TSV, allowing the solution to gravity drain from the TSV.
d. The target solution has negative temperature and void coefficients.

Active engineered controls:

a. A neutron flux detection system is provided for the TSV. The neutron flux detection instrumentation automatically actuates safety equipment at predetermined flux level trip setpoints.
b. The TSV is filled through two redundant fill valves in series. Both fill valves are automatically closed or are blocked from opening if the neutron flux level exceeds the flux level trip setpoints or the system is not in fill mode.
c. Automatically-actuated TSV dump valves and a TSV dump tank are provided. Two parallel dump valves are provided, each of which is actuated if the neutron flux level exceeds the flux level trip setpoints.

Administrative controls:

a. Measurement and independent verification of uranium concentration in the target solution occurs prior to being transferred to the TSV.
b. During the startup process, operators verify correct flux levels using procedure-based acceptance criteria.

The nuclear criticality safety program for operations outside the TSV is discussed in Section 6b.3. The criticality safety controls outside the TSV include criticality-safe equipment designs to preclude placing fissile material in a favorable configuration for criticality, and measurement and independent verification of uranium concentration for transfers from safe geometry to unsafe geometry tanks.

1.2.5 POTENTIAL ACCIDENTS AT THE FACILITY

Potential design basis accidents (DBAs) at the SHINE facility were identified by the application of hazard analysis methodologies to evaluate the preliminary design of the facility and processes for potential hazards, initiating events (IEs), scenarios, and associated controls. These methodologies were applied to both the IF and the RPF. Two hazard analysis methodologies used are:

- Hazards and operability study (HAZOPS).
- Preliminary design hazard analysis (PHA).

This resulted in a preliminary design Integrated Safety Analysis (ISA). The ISA was prepared in accordance with NUREG-1513, Integrated Safety Analysis Guidance Document Format and Content. The list of accident categories and IEs identified in the NUREG-1537, Part 1, and the associated Final ISG Augmenting NUREG-1537, Part 1, were the basis for the identification of potential DBAs.

The following accident categories and IEs are addressed for the SHINE facility. Some are applicable to the IF, some are applicable to the RPF, and some are applicable to both.

- Maximum hypothetical accident (MHA).
- Insertion of excess reactivity/inadvertent criticality.
- Reduction in cooling.
- Mishandling or malfunction of target solution.
- Loss of off-site power.
- External events.
- Mishandling or malfunction of equipment affecting the primary system boundary.
- Large undamped power oscillations.
- Detonation and deflagration in the primary system boundary.
- Unintended exothermic chemical reactions other than detonation.
- Primary system boundary system interaction events.
- Facility-specific events
    - Inadvertent exposure to neutrons from the neutron driver.
    - IF fires.
    - Tritium purification system malfunction
- Critical equipment malfunctions.
- Inadvertent nuclear criticality in the RPF.
- RPF fire.
- Accidents with hazardous chemicals.

These accidents are addressed in Chapter 13.

1.3 GENERAL DESCRIPTION OF THE FACILITY

The SHINE production facility building consists of an IF, RPF, shipping and receiving area, and other areas that contain various support systems and equipment.

Floor plan and section drawings of the facility showing the arrangements of the major structures and equipment are provided in Figures 1.3-1, 1.3-2, and 1.3-3.

The SHINE facility site layout is provided in Figure 1.3-4. The RCA of the SHINE facility consists of the IF and the RPF (see Figure 1.3-5).

1.3.1 GEOGRAPHICAL LOCATION

The SHINE facility is located on the south side of the City of Janesville corporate boundaries, in Rock County, Wisconsin. The SHINE facility is centered at 42° 37’ 26.9” N latitude, and 89° 1’ 29.5” W longitude.

1.3.2 PRINCIPAL CHARACTERISTICS OF THE SITE

The SHINE site consists of an undeveloped, approximately 91-acre (ac.) (36.8-hectare [ha]) parcel that has been historically farmed. Safety-related structures are located within a rectangular area located near the center of the property. The region of the SHINE site is entirely contained within Rock County, Wisconsin. The dominant land use in the region is agricultural/ cultivated crops. The northern limits of the City of Beloit are located approximately 3.7 miles (mi.) (6.0 kilometers [km]) to the south. Principal characteristics of the site are further described in Chapter 2.

1.3.3 PRINCIPAL DESIGN CRITERIA, OPERATING CHARACTERISTICS, AND SAFETY SYSTEMS

Safety significant SSCs within the facility are separated into two classifications. The safety significant SSCs in the IF are classified as safety-related. The safety significant SSCs in the RPF are classified as IROFS. The SHINE facility is licensed under 10 CFR 50. See Subsection 1.2.4.1 for the definitions of safety-related and IROFS.

1.3.3.1 Principal Design Criteria

Design criteria for the facility are addressed in Section 3.1. Design criteria for systems and components are addressed in Section 3.5.

1.3.3.2 Operating Characteristics

The IUs are operated in a batch mode with an approximate week-long operating cycle. An operating cycle includes the following steps: receipt of uranyl sulfate target solution from the RPF, transfer to the TSV, operation of the subcritical assembly at full power for approximately 5.5 days, shut down, and transfer of the irradiated target solution to the RPF for isotope extraction. During the full power operation of the subcritical assembly system, the target solution is maintained in a subcritical state.

The RPF also operates in a batch mode. The major operating steps include the following: preparation of uranyl sulfate solution from recycled materials and/or from raw feed materials, extraction of Mo-99 from processed target solution, purification of extracted Mo-99, and packaging of Mo-99 for shipment to customers.

Operating characteristics of the IUs are discussed in more detail in Section 4a2. Operating characteristics of the RPF are discussed in more detail in Section 4b.

1.3.3.3 Facility Systems

The IF consists of eight IUs. Each IU consists of a neutron driver assembly system (NDAS), a subcritical assembly system (SCAS), a light water pool system (LWPS), TOGS, and related support systems.

The neutron driver is an accelerator-based assembly that accelerates a deuterium stream into a tritium gas target chamber. The resulting fusion reaction produces 14 million electron volt (MeV) neutrons, which move outward from the tritium target chamber in all directions. The neutron driver is addressed in Section 4a2.3. The neutron driver is not a safety-related system.

The neutron driver is located directly above the subcritical assembly. Most of the neutrons enter the SCAS, where they are slowed down to thermal energy. The resulting thermal neutron flux interacts with the uranium-235 (U-235) atoms in the target solution, causing the atoms to fission. Each SCAS has four major components: the TSV, the neutron multiplier, the subcritical assembly support structure (SASS), and the TSV dump tank. The SCAS and its subcomponents are described in Section 4a2.2.

The SCAS is located inside of the light water pool, part of the LWPS. The LWPS is addressed in Sections 4a2.4 and 5a2.2. The TOGS removes the off-gas from the TSV and is described in Section 4a2.8.

The function of the RPF is to extract, purify, and package Mo-99 for the end users. Additionally, the RPF prepares feed target solution for the IU. The RPF includes facility features and systems where the processes that support the IUs are performed, and where processing of the irradiated target solution occurs. The major systems and processes are described below.

The target solution preparation system (TSPS) prepares target solution from either uranium metal or from recycled target solution. The TSPS is described in Section 4b.1.3.1.

The molybdenum extraction and purification system (MEPS) receives irradiated target solution, processes the target solution to extract the Mo-99, then purifies the product into its final form prior to packaging and shipping. The MEPS is described in Section 4b.1.3.2.

The uranyl nitrate conversion system (UNCS) periodically performs additional processing of the irradiated target solution after the Mo-99 has been extracted. This processing includes conversion of the uranyl sulfate target solution to uranyl nitrate, cleanup of the target solution by removal of fission products, and conversion of the cleaned up target solution to uranium oxide that is then supplied to the TSPS as a feed material to produce new target solution. The UNCS is described in Section 4b.1.3.3.

The process vessel vent system (PVVS) collects and processes acidic and noble gases from the vents of process vessels that handle the main process fluids. This system is briefly discussed in Subsection 4b.1.3.5 and discussed in detail in Section 9b.6.

The molybdenum isotope product packaging system (MIPS) receives the Mo-99 from MEPS and packages it for shipment to the customers. This system is addressed briefly in Section 4b.1.3.4 and in detail in 9b.7.1.

Other systems located in the RPF are briefly addressed in Section 4b.1 and are discussed in more detail in the following chapters of this report.

Refer to Table 3.1-1 for the system safety classifications.

The legend for process flow diagrams provided in the PSAR is found in Figure 1.3-6.

1.3.4 ENGINEERED SAFETY FEATURES

Engineered safety features (ESFs) are SSCs of the facility that mitigate design basis events or accidents.

ESFs for the IF are addressed in Section 6a2.2 and Table 6a2.2-1. ESFs in the IF are related to confinement of radiological material.

Confinement is the term used to describe the low-leakage boundary that surrounds radioactive materials released during an accident and the associated RCA ventilation system (RV). Confinement systems are designed to localize release of radioactive material to controlled areas in normal operational states and mitigate the consequences of DBAs. Radiation protection control features such as adequate shielding and the RV minimize hazards normally associated with radioactive materials. The principal design and safety objective of the confinement systems is to protect on-site personnel, the public, and the environment. The second design objective is to minimize reliance on administrative or complex active engineering controls to provide a confinement system that is as simple and fail-safe as reasonably possible.

The TSV, TSV dump tank, TOGS, and associated components act as the primary pressure boundary and are safety-related SSCs. These ESFs act as the primary fission product boundary and are referred to as the primary system boundary (PSB). The confinement boundary of the IU cell and TOGS shielded cell encloses the PSB.

Confinement of the IU cells is achieved through the RV, the engineered safety feature actuation system (ESFAS), and the biological shielding provided by the steel and concrete structures comprising the walls, roofs, and penetrations of the IU cell and TOGS shielded cell. Shielding of the IU cells is discussed in detail in Section 4a2.5.

ESFs outside the IF are addressed in Section 6b.2 and Table 6b.2-1. The ESFs are related to confinement of radiological material and hazardous material. The RPF confinement areas include hot cell enclosures and gloveboxes for process operations and trench and vault enclosures for process tanks and piping.

Confinement is achieved through RV, radiological integrated control system (RICS), and biological shielding provided by the steel and concrete structures comprising the walls, roofs, and penetrations of the hot cells. Shielding of the hot cells is discussed in detail in Subsection 4b.2.2.

SSCs that perform an ESF function are classified as safety-related.

1.3.5 INSTRUMENTATION, CONTROL, AND ELECTRICAL SYSTEMS

The TSV process control system (TPCS) controls the operation of the TSV. The TSV is protected by the TSV reactivity protection system (TRPS). These are addressed in Sections 7a2.3 and 7a2.4, respectively.

Control and protection systems associated with the RPF are addressed in Section 7b.

Design features of the control consoles and display instrumentation, and the radiation monitoring systems for both the IU and the RPF, are addressed in Chapter 7. Radiation monitoring systems include the criticality accident and alarm system (CAAS), the radiation area monitoring system (RAMS), and the continuous air monitoring system (CAMS).

The SHINE facility has one common normal electrical supply system, which provides power to the IF, the RPF, and other support buildings. Power service is provided by the local utility via off-site feeds. A standby diesel generator provides power for asset protection to selected loads in the event of a loss of off-site power. These systems are described in Section 8a2.1.

Emergency electrical power for the SHINE facility is provided by a common emergency power system. A Class 1E uninterruptible electrical power supply system (UPSS) is provided for the facility. This system consists of two independent trains, each consisting of a 250 volts-direct current (VDC) battery system with associated charger, inverter, and distribution system. This system is described in Section 8a2.2.

1.3.6 TSV COOLING AND OTHER AUXILIARY SYSTEMS

Primary cooling for the TSV and related components is provided by the LWPS and the primary closed loop cooling system (PCLS). The TSV and related components are submerged in the light water pool. The LWPS is addressed in Sections 5a2.2 and 4a2.4. The PCLS is addressed in Section 5a2.2. The light water pool and primary closed loop cooling make-up system (MUPS) supports the LWPS and the PCLS. This system is addressed in Section 5a2.5.

Primary cooling for the RPF and removal of heat from both the LWPS and the PCLS is provided by the radioisotope process facility cooling system (RPCS). This system is discussed in Section 5a2.3.

Ventilation for both the IF and the RPF is provided by the RV. This ventilation system is described in Section 9a2.1.

Equipment and processes related to handling and storage of target solution are addressed in Section 9a2.2. Equipment and processes related to handling and storage of byproduct material and SNM are addressed in Section 9a2.5.

The tritium purification system (TPS) is provided to process gas from the tritium target of the neutron drivers. This system separates the deuterium from the tritium, and returns a purified tritium stream. This system is addressed in Section 9a2.7.1.

Fire protection systems and programs are addressed in Section 9a2.3. Communications systems are addressed in Section 9a2.4. Other auxiliary systems are also addressed in Sections 9a2 and 9b.

1.3.7 RADIOACTIVE WASTE MANAGEMENT AND RADIATION PROTECTION

The SHINE facility 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 Parts 19, 20, and 70. This program includes the elements of an ALARA program, radiation monitoring and surveying, exposure control, dosimetry, contamination control, and environmental monitoring. This program is addressed in Subsection 11.1.2.

The SHINE facility has a respiratory protection program to protect its workers from airborne contamination. This program is described in Section 11.3.

Control of gaseous, liquid, and solid radioactive wastes is provided by the PVVS, the aqueous radioactive liquid waste storage system (RLWS), the radioactive liquid waste evaporation and immobilization system (RLWE), the noble gas removal system (NGRS), and the solid radioactive waste packaging system (SRWP). Potentially radioactive drains are part of the radioactive drain system (RDS). These systems are described in Sections 9b.6 and 9b.7.

1.3.8 EXPERIMENTAL FACILITIES AND CAPABILITIES

The SHINE facility does not include experimental facilities or capabilities.

1.3.9 RESEARCH AND DEVELOPMENT

10 CFR 50.34(a) requires that the Preliminary Safety Analysis Report identify those structures, systems or components of the facility, if any, which require research and development to confirm the adequacy of their design; and identification and description of the research and development program which will be conducted to resolve any safety questions associated with such structures, systems or components; and a schedule of the research and development program showing that such safety questions will be resolved at or before the latest date stated in the application for completion of construction of the facility.

SHINE will perform testing to validate the acceptable operating conditions for material and target solution compatibility at the Oak Ridge National Laboratory. Selected materials will be examined following irradiation testing at fluence levels expected in the operation of the target solution vessel for a 30 year life-time. The testing will include specific work involving irradiation in the corrosive environment to examine the effects on the properties of selected materials in an “as received” and “as fabricated” state to examine raw material and welded samples. This work will be completed prior to 12/31/16 which is the latest date for completion of construction of the facility.

1.4 SHARED FACILITIES AND EQUIPMENT

The SHINE facility does not share any systems or equipment with facilities not covered by this report.

The SHINE production facility building includes both the IF and the RPF. Although these are functionally separate, they share the same building. The SHINE facility includes the following structures:

- Production facility building (IF and RPF).
- Support facility building.
- Waste staging and shipping building.
- Diesel generator building.
- Administration building.
- Security station.

Some of the supporting systems identified in the above sections (e.g., the normal electrical supply system discussed in Subsection 1.3.5) support all functions of the SHINE facility.

1.5 COMPARISON WITH SIMILAR FACILITIES

1.5.1 COMPARISON OF PHYSICAL PLANT AND EQUIPMENT

As stated in Section 1.1, the SHINE facility uses new technology for the manufacture of medical isotopes. The IU, consisting of the neutron driver, subcritical assembly, light water pool, TOGS, and other supporting systems represent the new technology. As such, there are no similar facilities that compare to the IUs. These systems and components are discussed in Section 4a2.

The neutron driver in particular has specifically been developed for use on this project. The subcritical assembly, consisting of the TSV, neutron multiplier, SASS, and TSV dump tank, is also a new design. The neutron driver is discussed in Section 4a2.3.

The RPF is of conventional design. In this facility, the irradiated target solution is processed in hot cells to separate and purify the Mo-99 produced. The hot cell design is conventional and is similar to the design used in many other facilities. The RPF is discussed in Section 4b.

1.5.2 COMPARISON OF CHEMICAL PROCESSES

1.5.2.1 Molybdenum Extraction

The SHINE facility molybdenum (Mo) extraction system uses [Proprietary Information] to selectively adsorb Mo from the irradiated target solution. There are currently no U.S. Nuclear Regulatory Commission (NRC) or U.S. Department of Energy (DOE) facilities that use this specific process. However, the use of solid sorbents to remove specific components from an aqueous solution has been widely researched and demonstrated on a commercial scale.

In particular, cesium-137 and strontium-90 are typically isotopes that are removed from aqueous streams, due to their gamma emission driving worker and public dose rates. Cesium can be removed by crystalline silico-titanate, or sodium titanosilicate followed by alumina montmorillonite clay. Strontium is removed by sodium titanosilicate, followed by titanium silicate pharmacosiderites. These processes have been researched extensively; however, no facilities utilizing these technologies have been approved by DOE or NRC.

At Sellafield in the United Kingdom, the Site Ion Exchange Effluent Plant (SIXEP) uses clinoptilolite to remove cesium and strontium from aqueous process streams. Clinoptilolite is a naturally occurring clay-like material. The SIXEP facility has been in operation since 1985.

1.5.2.2 Molybdenum Purification

The SHINE Mo purification process is very similar to the Cintichem process developed in the 1950s and 1960s by Union Carbide. The SNM license was transferred from the Union Carbide Corporation to Cintichem, Inc. in 1984. Cintichem, Inc. operated the process until 1990 as a means to purify Mo-99 for use as a medical isotope. There are no NRC or DOE licensed facilities currently using this technology. The process used by Union Carbide and Cintichem, Inc. generated Mo-99 produced by fission in HEU solid targets. The SHINE process produces Mo-99 derived from irradiation of LEU target solution. The chemistry of the process has been adjusted slightly to accommodate the change in chemical and isotopic composition due to the switch from HEU to LEU.

The purification process is a small scale, batch chemical procedure performed in laboratory glassware. The principal engineered safety features associated with the purification process are shielding and confinement associated with reducing facility worker dose. These are unchanged between the previous deployment of the Cintichem process and the system employed at the SHINE facility. There is no instrumentation and control associated with the process system.

1.5.2.3 Uranyl Nitrate Conversion

The conversion of uranyl sulfate to uranyl nitrate is necessary to enable fission products to be removed from the uranium, in order to recycle the uranium within the target solution loop. The conversion step for the uranyl sulfate, utilizing [Proprietary Information], is not currently used in any NRC or DOE facilities.

1.5.2.4 Uranium Extraction

The uranium extraction (UREX) process is a modification of a widely-used uranium and plutonium separation and purification process known as plutonium and uranium extraction (PUREX). The PUREX process was developed in the late 1940s and uses tributyl phosphate (TBP) to selectively remove uranium and plutonium from a nitric acid solution typically containing a host of fission product and other actinide contaminants.

Due to the sensitive and confidential nature of information related to nuclear fuel reprocessing, design and operational details of PUREX facilities are not published. However, it is public knowledge that the PUREX process has been employed at a number of sites, both in the US and around the globe. Some are still in operation; others have been shut down. The principal locations with current or historical PUREX processes are:

a. Hanford, Washington.
b. Savannah River Site, South Carolina.
c. Idaho National Laboratory, Idaho.
d. West Valley, New York.
e. Radiochemical Engineering Development Center, Oak Ridge National Laboratory, Tennessee.
f. Sellafield, United Kingdom.
g. Mayak, Russia.
h. AREVA La Hague site, France.
i. Rokkasho, Japan.

The UREX process was developed as part of the Global Nuclear Energy Partnership (GNEP) as a means of recovering uranium from dissolved fuel solution, while leaving plutonium in the aqueous phase. This greatly reduces the fissile material proliferation potential of the process. UREX uses the same TBP solvent to complex and remove the uranium, but uses an additional component in the scrub solution to complex the plutonium and prevent it from dissolving in the organic phase. This additional component is acetohydroxamic acid (AHA).

The PUREX and UREX processes are liquid-liquid extraction operations, requiring multiple stages of contact to achieve the required product separation. There are several technologies used to accomplish this contacting and separation of the aqueous and organic phases. The

SHINE facility uses centrifugal contactors. This is the safest, most effective and most modern technology. Of the locations listed above, Savannah River and La Hague are known to use centrifugal contactor technology. Centrifugal contactors are the most compact design, compared to mixer-settlers and pulsed columns. This has the safety benefit of lower inventory, hence a smaller volume of material at risk.

As stated previously, the design and operational details of PUREX facilities are not published. However, one of the essential safety and control features of the process is ensuring adequate separation of the fission products from the uranium product, and adequate removal of uranium from the fission-product-containing raffinate. This is common to all the PUREX operations and the SHINE UREX design.

1.5.2.5 Evaporation and Thermal Denitration

Evaporation and thermal denitration of uranyl nitrate is most often associated with reprocessing. Hence design and operational details are not publicly available. The facilities listed above that employ the PUREX process also likely use evaporation and thermal denitration to convert the uranyl nitrate product to uranium oxide. The specific evaporation technology is dependent on the enrichment of the uranium being processed. The SHINE process uses a thin film evaporator, which is used for evaporation of LEU and HEU liquids, due to the low inventory of process fluid in the unit enabling a criticality-safe-by-geometry design.

The primary control within the evaporation systems is temperature control to maintain the temperature below 248 degrees Fahrenheit (°F) (120 degrees Celsius [°C]). The normal operating range for the evaporators is 230 to 239°F (110 to 115°C).

Thermal denitration of uranyl nitrate is most commonly performed in a fluidized bed reactor. This is due to the heat and mass transfer characteristics of this type of equipment compared to alternatives, such as a rotary calciner or wiped film evaporator. Fluidized bed thermal denitration is performed at all of the PUREX processing locations listed above.

There are no NRC-licensed uranyl nitrate evaporation and thermal denitration facilities in operation. Such facilities are operated in Ontario, Canada by Cameco. Information on uranyl nitrate evaporation and thermal denitration facilities approved by DOE is not available.

1.5.2.6 Waste Evaporation and Solidification

Evaporation is practiced worldwide as a means of reducing the volume of aqueous radioactive wastes. The submerged tube forced recirculation evaporator, used at the SHINE facility, is the most frequently used design for this process. This design offers operational flexibility to account for the variability in liquid waste composition and flowrate often encountered in radioactive waste processing. Heater tube fouling is also reduced, compared to alternative designs, by high tubeside velocities and a low temperature rise across the heater.

The DOE Hanford site includes a liquid waste evaporator, which is the submerged tube, forced recirculation design. Construction was completed in 1977, and the evaporator is anticipated to operate into at least the 2040s.

There are also radioactive liquid waste evaporators at other DOE sites, such as Savannah River, Idaho National Laboratory (INL) and Oak Ridge National Laboratory (ORNL). The design and operational specifics of these evaporators is not publicly available.

The Sellafield site in the United Kingdom uses submerged tube forced recirculation evaporators to reduce the volume of liquid wastes. Separate evaporation facilities are used to process high level liquid waste and intermediate level liquid waste. Design and operational details of other facilities around the world are not publicly available.

1.5.2.7 Tritium Purification System

Tritium is purified using the TCAP technology. TCAP was developed at the Savannah River Site to separate tritium from deuterium and protium. Other process equipment is used to support the TCAP separation, including impurity removal and tritium storage. TCAP and its supporting process equipment is known as the tritium purification system (TPS). TPS is similar in design to the processes within the following facilities:

a. Savannah River Site, South Carolina.
b. Laboratory for Laser Energetics, Rochester, New York.

Due to the sensitive and confidential nature of information relating to tritium production and purification, the design and operational details of these systems are not published. A comparison of the SHINE system with existing facilities is therefore not possible. The same is true of other tritium facilities around the globe.

1.5.3 COMPARISON OF SUPPORT SYSTEMS

Supporting systems, including ventilation, cooling water, waste processing, electrical power, and instrumentation and control are conventional in nature. In general, there are no unique features that warrant discussion here in Section 1.5. These systems are discussed in the corresponding chapters of this report.

1.6 SUMMARY OF OPERATIONS

The major operations to be performed in the SHINE facility are as follows:

- Target solution preparation from raw feed material (uranium metal).
- Target solution preparation from irradiated and processed target solution.
- Irradiation of target solution.
- Mo extraction from irradiated target solution.
- Mo purification.
- Target solution processing (cleanup).

Target solution preparation from raw feed material (uranium metal) involves the following processes. The raw feed material for the target solution consists of LEU metal. Raw uranium metal is converted to uranyl nitrate by dissolution in nitric acid. The uranyl nitrate is converted to uranium oxide by the thermal denitration process. Uranium oxide is dissolved in sulfuric acid to produce the uranyl sulfate target solution. After initial start up of the facility, receipt of uranium will be infrequent. Preparation of target solution from uranium metal will be infrequent, only as necessary to make up for losses.

The IF consists of eight IUs. Each IU is operated for a week-long cycle. The operating cycle includes the following steps: Prepared target solution is transferred to the target solution hold tank, and then into the TSV. The volume of uranyl sulfate solution in the TSV is nominally [Proprietary Information]. The neutron driver is energized and ramped up to full power. The subcritical assembly is operated at full power for approximately 5.5 days. The unit is shut down and the target solution is allowed to decay. The target solution is transferred to the RPF for processing.

Molybdenum extraction is performed in a hot cell in the RPF. Mo extraction from irradiated target solution involves passing the irradiated target solution through [Proprietary Information] adsorbent. The Mo and other fission products are adsorbed onto the [Proprietary Information]. Mo is eluted using a base. The eluate is dried and redissolved in nitric acid. The resulting Mo-99 product is transferred to the Mo-99 purification system. The [Proprietary Information] for the Mo extraction process is contained in a packed column configuration. Each column is replaced after a single TSV batch has been processed through it.

Molybdenum purification is performed in a hot cell in the RPF. The Mo-99 product is purified in a lab glassware system. The glassware is disposed of after each TSV batch.

A maximum of [Proprietary Information] TSV volumes [Proprietary Information] are processed through the target solution cleanup system [Proprietary Information]. The irradiated uranyl sulfate target solution is converted to uranyl nitrate to enable fission products to be separated using the UREX process. The irradiated target solution is reacted with [Proprietary Information]. This reaction converts the uranium from a sulfate to a nitrate. The resulting solution is converted to uranium oxide using the thermal denitration process. The cleaned-up uranium oxide is then used as feed material for target solution preparation, as described above.

The SHINE facility produces up to 8200 6-day curies of Mo-99 per week.

The fission product inventory from operation of the facility is provided in Subsection 11.1.1. Normal effluent release pathways from the SHINE facility to the environment are discussed in Subsection 11.1.7.2.

1.7 COMPLIANCE WITH THE NUCLEAR WASTE POLICY ACT OF 1982

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

1.8 FACILITY MODIFICATIONS AND HISTORY

This report is an application for construction of the SHINE facility. As there are no existing facilities, there have been no modifications, and there is no history to report. Therefore, this section is not applicable to the SHINE facility.

1.9 REFERENCES

ANS, 2007. ANSI/ANS 8.1, Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, 2007.

DOE, 1996. U. S. Department of Energy, DOE-STD-3014-2006, Accident Analysis for Aircraft Crash Into Hazardous Facilities, October 1996, Reaffirmation May 2006.