CHAPTER 3

DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
BE	best estimate
CAAS	criticality accident alarm system
CAMS	continuous air monitoring system
cm	centimeter
DOE	U.S. Department of Energy
E/W	east-west
ELTG	emergency lighting system
ESFAS	engineered safety features actuation system
FACS	facility access control system
FCHS	facility chilled water system
FCRS	facility chemical reagent system

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
FDCS	facility data and communications system
FDWS	facility demineralized water system
FFPS	facility fire detection and suppression system
FGLP	facility grounding and lightning protection system
FHWS	facility heating water system
FNHS	facility nitrogen handling system
FPWS	facility potable water system
FSDS	facility sanitary drains system
FSTR	facility structure
ft.	feet
ft^2	square feet
ft^3	cubic feet
FVZ4	facility ventilation zone 4
HCFD	hot cell fire detection and suppression system
HVAC	heating, ventilation, and air conditioning
Hz	hertz

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
IAEA	International Atomic Energy Agency
ICBS	irradiation cell biological shield
IEEE	Institute of Electrical and Electronics Engineers
IF	irradiation facility
in.	inch
ISRS	in-structure response spectra
IU	irradiation unit
IXP	iodine and xenon purification and packaging
kg/m^3	kilogram per cubic meter
kPa	kilopascal
kph	kilometers per hour
LABS	quality control and analytical testing laboratories
LB	lower bound
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
LWPS	light water pool system

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
m	meter
m^3	cubic meter
m/s	meters per second
MEPS	molybdenum extraction and purification system
MHS	material handling system
MIPS	molybdenum isotope product packaging system
mph	miles per hour
N/S	north-south
N2PS	nitrogen gas purge system
NDAS	neutron driver assembly system
NFDS	neutron flux detection system
NFPA	National Fire Protection Association
NPSS	normal electrical power supply system
NSC	NDAS service cell
PCHS	process chilled water system
PCLS	primary closed loop cooling system

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
PFBS	production facility biological shield system
PGA	peak ground acceleration
PICS	process integrated control system
PMF	probable maximum flood
PMP	probable maximum precipitation
psf	pounds per square foot
psi	pounds per square inch
PVVS	process vessel vent system
QME	qualification of active mechanical equipment
RAMS	radiation area monitoring system
RCA	radiologically controlled area
RDS	radioactive drain system
RLWI	radioactive liquid waste immobilization
RLWS	radioactive liquid waste storage
RPCS	radioisotope process facility cooling system
RPF	radioisotope production facility

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
RRS	required response spectrum
RVZ1	radiological ventilation system zone 1
RVZ2	radiological ventilation system zone 2
RVZ3	radiological ventilation system zone 3
SCAS	subcritical assembly system
SGS	standby generator system
SRMS	stack release monitoring system
SRP	Standard Review Plan for the Review of Safety Analysis for Nuclear Power Plants
SRSS	square root of the sum of the squares
SRWP	solid radioactive waste packaging
SSC	structure, system, or component
SSE	safe shutdown earthquake
SSI	soil-structure interaction
SWRA	Southern Wisconsin Regional Airport
TEDE	total effective dose equivalent
TOGS	TSV off-gas system

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
TPS	tritium purification system
TRPS	TSV reactivity protection system
TSPS	target solution preparation system
TSSS	target solution staging system
TSV	target solution vessel
UB	upper bound
UPSS	uninterruptible electrical power supply system
URSS	uranium receipt and storage system
VTS	vacuum transfer system
ZPA	zero period acceleration

CHAPTER 3 – DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

3.1 DESIGN CRITERIA

Structures, systems, and components (SSCs) present in the SHINE facility are identified in Tables 3.1-1 and 3.1-2, including the applicable FSAR section(s) which describe each SSC and the applicable SHINE design criteria. Design criteria derived from external codes, guides, and standards specific to the design, construction, or inspection of SSCs are included in the applicable FSAR section describing those SSCs. For each SSC, the FSAR section identifies location, function, modes of operation, and type of actuation for specific SSCs, as applicable.

<u>Nuclear Safety Classification</u>

Safety-related SSCs at SHINE are those physical SSCs whose intended functions are to prevent accidents that could cause undue risk to health and safety of workers and the public; and to control or mitigate the consequences of such accidents.

Acceptable risk is achieved by ensuring that events are highly unlikely or by reducing consequences less than the SHINE safety criteria. The SHINE safety criteria are:

- An acute worker dose of five rem or greater total effective dose equivalent (TEDE).
- An acute dose of 500 millirem or greater TEDE to any individual located outside the owner controlled area.
- An intake of 30 milligrams or greater of uranium in a soluble form by any individual located outside the owner controlled area.
- An acute chemical exposure to an individual from licensed material or hazardous chemicals produced from licensed material that could lead to irreversible or other serious, long-lasting health effects to a worker or could cause mild transient health effects to any individual located outside the owner controlled area.
- Criticality in the radioisotope production facility (RPF).
- Loss of capability to reach safe shutdown conditions.

Some SSCs are nonsafety-related but perform functions that impact safety-related SSCs. These nonsafety-related SSCs have design basis requirements necessary to prevent unfavorable interactions with safety-related SSCs due to failure of the nonsafety-related SSCs.

Safety-related SSCs are identified in Table 3.1-1 and nonsafety-related SSCs are identified in Table 3.1-2.

<u>SHINE Design Criteria</u>

The SHINE facility uses design criteria to ensure that the SSCs within the facility demonstrate adequate protection against the hazards present. The design criteria are selected to cover:

- The complete range of irradiation facility and radioisotope production facility operating conditions.
- The response of SSCs to anticipated transients and potential accidents.
- Design features for safety-related SSCs including redundancy, environmental qualification, and seismic qualification.
- Inspection, testing, and maintenance of safety-related SSCs.

- Design features to prevent or mitigate the consequences of fires, explosions, and other manmade or natural conditions.
- Quality standards.
- Analyses and design for meteorological, hydrological, and seismic effects.
- The bases for technical specifications necessary to ensure the availability and operability of required SSCs.

The SHINE design criteria are described in Table 3.1-3.

Key terms used in Table 3.1-3 include primary system boundary, primary confinement boundary, and process confinement boundary, which are defined in Sections 4a2.2, 6a2.2, and 6b.2, respectively.

Table 3.1-1 – Safety-Related Structures, Systems, and Components (Sheet 1 of 2)

Structure, System, or Component (SSC)	Acronym	Section	Applicable Design Criteria
Engineered safety features actuation system	ESFAS	7.1.3 7.5	13-19, 37-39
Facility structure	FSTR	3.4.2	2, 6
Irradiation cell biological shield	ICBS	4a2.1 4a2.5	29-36
Iodine and xenon purification and packaging	IXP	4b.1.3 4b.3.1	9, 33, 36-37, 39
Light water pool system	LWPS	4a2.1 4a2.4.2	25, 29-32, 36
Molybdenum extraction and purification system	MEPS	4b.1.3 4b.3	27, 33, 36, 37, 39
Normal electrical power supply system	NPSS	8a2.1	27, 28
Neutron flux detection system	NFDS	4a2.1 7.1.7 7.8	13-19
Nitrogen purge system	N2PS	6b.2.3 9b.6.2	39
Primary closed loop cooling system	PCLS	4a2.1 5a2.2	9, 12, 21, 29, 33
Process vessel vent system	PVVS	4b.1.3 9b.6.1	35, 39
Production facility biological shield	PFBS	4b.2	29-32, 36
Radioactive drain system	RDS	9b.7.6	36, 37
Radioactive liquid waste immobilization	RLWI	9b.7.3	35-38
Radioactive liquid waste storage	RLWS	4b.1.3 9b.7.4	35-36, 38-39
Radiological ventilation zones 1, 2, and 3	RVZ1 RVZ2 RVZ3	9a2.1	29, 30, 32-36
Subcritical assembly system	SCAS	4a2.1 4a2.2	9-11, 20, 22-25, 29-34, 36, 39

Table 3.1-1 – Safety-Related Structures, Systems, and Components (Sheet 2 of 2)

Structure, System, or Component (SSC)	Acronym	Section	Applicable Design Criteria
Target solution preparation system	TSPS	4b.1.3 4b.4.2 9b.2.3,	29-32, 36-37
Target solution staging system	TSSS	4b.1.3 4b.4 9b.2.4	36, 37, 39
Tritium purification system	TPS	4a2.1 9a2.7.1	12, 29-35, 38
TSV off-gas system	TOGS	4a2.1 4a2.8	12, 20, 22-24, 29, 33-34, 37, 39
TSV reactivity protection system	TRPS	7.1.2 7.4	13-19, 38-39
Uninterruptible electrical power supply system	UPSS	8a2.2	29-30
Uranium receipt and storage system	URSS	4b.1.3 4b.4.2	29-33, 36-37
Vacuum transfer system	VTS	4b.1.3 9b.2.5	36-37

Note 1: This table contains SSCs where at least one constituent component is classified as safety-related.

Note 2: The generally-applicable design criteria 1-8 from Table 3.1-3 are not specifically listed even though they are generally applicable to most SSCs, with the exception of criterion 2 and criterion 6, which are specifically applied to the FSTR due to the unique relationship of these criteria to the facility structure.

Note 3: Instrumentation, control and protection system-related design criteria 13-19 from Table 3.1-3 are only applied to the ESFAS, TRPS, and NFDS (i.e., the safety-related instrumentation and control systems). Other systems that include safety-related instrumentation that provides input to the safety-related instrumentation and control systems implement these criteria via flow down requirements from the safety-related instrumentation and control systems.

Table 3.1-2 – Nonsafety-Related Structures, Systems, and Components (Sheet 1 of 2)

Structure, System, or Component (SSC)	Acronym	Section	Applicable Design Criteria
Criticality accident alarm system	CAAS	6b.3.2 7.7.6	8, 37
Continuous air monitoring system	CAMS	7.7.4	13, 38
Facility access control system	FACS	12.8	-
Facility chemical reagent system	FCRS	9b.7.10	7
Facility chilled water supply and distribution system	FCHS	9a2.1.3	26
Facility data and communications system	FDCS	9a2.4	8
Facility demineralized water system	FDWS	5a2.6	33
Facility fire detection and suppression system	FFPS	9a2.3	-
Facility heating water system	FHWS	9a2.1.4	-
Facility nitrogen handling system	FNHS	9b.7.8	33
Facility potable water system	FPWS	9b.7.7	-
Facility sanitary drains system	FSDS	9b.7.9	-
Facility ventilation zone 4	FVZ4	9a2.1	-
Hot cell fire detection and suppression system	HCFD	9a2.3	-
Material handling system	MHS	9b.7.2	-
Molybdenum isotope product packaging system	MIPS	9b.7.1	-
NDAS service cell	NSC	9a2.7.2	-
Neutron driver assembly system	NDAS	4a2.1 4a2.3	33
Process chilled water system	PCHS	5a2.4	26
Process integrated control system	PICS	7.3	6, 13
Quality control and analytical testing laboratories	LABS	9b.2 9b.5	-

Table 3.1-2 – Nonsafety-Related Structures, Systems, and Components (Sheet 2 of 2)

Structure, System, or Component (SSC)	Acronym	Section	Applicable Design Criteria
Radiation area monitoring system	RAMS	7.7.3	13, 38
Radioisotope process facility cooling system	RPCS	5a2.3	26
Solid radioactive waste packaging	SRWP	9b.7.5	-
Stack release monitoring system	SRMS	7.7.5	13, 38
Standby generator system	SGS	8a2.2	27-28

Note 1: The generally-applicable design criteria 1-8 from Table 3.1-3 are not specifically listed unless they have a unique relationship with a particular SSC. See corresponding FSAR section(s) for detailed discussions of SSC design.

Table 3.1-3 – SHINE Design Criteria
(Sheet 1 of 11)

Generally-Applicable Design Criteria
Criterion 1 – Quality standards and records Safety-related structures, systems, and components (SSCs) are designed, fabricated, erected, and tested to quality standards commensurate with the safety functions to be performed. Where generally recognized codes and standards are used, they are identified and evaluated to determine their applicability, adequacy, and sufficiency and are supplemented or modified as necessary to ensure a quality product in keeping with the required safety function. A quality assurance program is established and implemented in order to provide adequate assurance that these SSCs satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection and testing of safety-related SSCs are maintained by or under the control of SHINE throughout the life of the facility.
Criterion 2 – Natural phenomena hazards The facility structure supports and protects safety-related SSCs and is designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches as necessary to prevent the loss of capability of safety-related SSCs to perform their safety functions. Safety-related SSCs are designed to withstand the effects of earthquakes without loss of capability to perform their safety functions.
Criterion 3 – Fire protection Safety-related SSCs are designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials are used wherever practical throughout the facility, particularly in locations such as confinement boundaries and the control room. Fire detection and suppression systems of appropriate capacity and capability are provided and designed to minimize the adverse effects of fires on safety-related SSCs. Firefighting systems are designed to ensure that their rupture or inadvertent operation does not significantly impair the safety capability of these SSCs.

Table 3.1-3 – SHINE Design Criteria
(Sheet 2 of 11)

Criterion 4 – Environmental and dynamic effects Safety-related SSCs are designed to perform their functions with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. These SSCs are appropriately protected against dynamic effects and from external events and conditions outside the facility.
Criterion 5 – Sharing of structures, systems, and components Safety-related SSCs are not shared between irradiation units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions.
Criterion 6 - Control room A control room is provided from which actions can be taken to operate the irradiation units safely under normal conditions and to perform required operator actions under postulated accident conditions.
Criterion 7 - Chemical protection The design provides 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.
Criterion 8 - Emergency capability The design provides emergency capability to maintain control of: 1) licensed material and hazardous chemicals produced from licensed material; 2) evacuation of on-site personnel; and 3) on-site emergency facilities and services that facilitate the use of available off-site services.

Table 3.1-3 – SHINE Design Criteria
(Sheet 3 of 11)

Subcritical Assembly Design Criteria
Criterion 9 - Subcritical assembly design The subcritical assembly system, target solution vessel off-gas system, and primary closed loop cooling system are designed with appropriate margins to assure that target solution design limits are not exceeded during conditions of normal operation, including the effects of anticipated transients.
Criterion 10 - Subcritical assembly inherent protection The subcritical assembly system is designed so that the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.
Criterion 11 - Suppression of subcritical assembly power oscillations The subcritical assembly system is designed to ensure that power oscillations that can result in conditions exceeding target solution design limits can be reliably and readily detected and suppressed.
Criterion 12 - Reactivity limits The target solution vessel (TSV) off-gas system, primary closed loop cooling system, and the TSV fill subsystem are designed with appropriate limits on the potential amount and rate of reactivity increase to ensure that the effects of postulated reactivity accidents can neither (1) result in damage to the primary system boundary greater than limited local yielding nor (2) sufficiently disturb the TSV, its support structures or other TSV internals to impair significantly the capability to drain the TSV. These postulated reactivity accidents include consideration of excess target solution addition, changes in primary cooling temperature, changes in primary system pressure, and deflagration or detonation in the primary system boundary.

Table 3.1-3 – SHINE Design Criteria
(Sheet 4 of 11)

Instrumentation, Control, and Protection Systems Design Criteria

Criterion 13 - Instrumentation and controls

Instrumentation is provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated transients, and for postulated accidents as appropriate to ensure adequate safety, including those variables and systems that can affect the fission process, the integrity of the primary system boundary, the primary confinement and its associated systems, and the process confinement boundary and its associated systems. Appropriate controls are provided to maintain these variables and systems within prescribed operating ranges.

Criterion 14 - Protection system functions

The protection systems are designed to:

1) initiate, automatically, the operation of appropriate systems to ensure that specified acceptable target solution design limits are not exceeded as a result of anticipated transients; and
2) sense accident conditions and to initiate the operation of safety-related systems and components.

Criterion 15 - Protection system reliability and testability

The protection systems are designed for high functional reliability and inservice testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection systems are sufficient to ensure that:

1) no single failure results in loss of the protection function, and
2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated.

The protection systems are designed to permit periodic testing, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.

Table 3.1-3 – SHINE Design Criteria
(Sheet 5 of 11)

Criterion 16 - Protection system independence The protection systems are designed to ensure that the effects of natural phenomena, and of normal operating, maintenance, testing, and postulated accident conditions on redundant channels do not result in loss of the protection function or are demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, are used to the extent practical to prevent loss of the protection function.
Criterion 17 - Protection system failure modes The protection systems are designed to fail into a safe state if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments are experienced.
Criterion 18 - Separation of protection and control systems The protection system is separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel that is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems is limited to assure that safety is not significantly impaired.
Criterion 19 - Protection against anticipated transients The protection systems are designed to ensure an extremely high probability of accomplishing their safety functions in the event of anticipated transients.

Table 3.1-3 – SHINE Design Criteria
(Sheet 6 of 11)

Primary System Boundary Design Criteria
Criterion 20 - Primary system boundary The primary system boundary is designed, fabricated, erected, and tested to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.
Criterion 21 - Primary closed loop cooling system design The primary closed loop cooling system is designed with sufficient margin to ensure that the design conditions of the primary system boundary are not exceeded during any condition of normal operation, including anticipated transients.
Criterion 22 - Quality of primary system boundary Components that are part of the primary system boundary are designed, fabricated, erected, and tested to the highest quality level practical. Means are provided for detecting and, to the extent practical, identifying the location of the source of primary system boundary leakage.
Criterion 23 - Fracture prevention of primary system boundary The primary system boundary is designed with sufficient margin to ensure that when stressed under operating, maintenance, testing, and postulated accident conditions: 1) the boundary behaves in a nonbrittle manner, and 2) the probability of rapidly propagating fracture is minimized. The primary system boundary design reflects consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining: 1) material properties, 2) the effects of irradiation on material properties, and 3) steady state and transient stresses.

Table 3.1-3 – SHINE Design Criteria
(Sheet 7 of 11)

Criterion 24 - Inspection of primary system boundary The primary system boundary design includes provisions for in-service inspection to ensure structural and leak tight integrity, and an appropriate material surveillance program for the primary system boundary.
Criterion 25 - Residual heat removal The light water pool is provided to remove residual heat. The system safety function is to transfer fission product decay heat and other residual heat from the target solution vessel dump tank at a rate such that target solution design limits and the primary system boundary design limits are not exceeded.
Criterion 26 - Cooling water The radioisotope process facility cooling system and process chilled water system are provided to transfer heat from safety-related SSCs to the environment, which serves as the ultimate heat sink.

Table 3.1-3 – SHINE Design Criteria
(Sheet 8 of 11)

Electric Power Systems Design Criteria

Criterion 27 - Electric power systems

An on-site electric power system and an off-site electric power system are provided to permit functioning of safety-related SSCs. The safety functions are to provide sufficient capacity and capability to assure that:

1) target solution design limits and primary system boundary design limits are not exceeded as a result of anticipated transients, and
2) confinement integrity and other vital functions are maintained in the event of postulated accidents.

The on-site uninterruptible electric power supply and distribution system has sufficient independence, redundancy, and testability to perform its safety functions assuming a single failure.

Provisions are included to minimize the probability of losing electric power from the uninterruptible power supply as a result of or coincident with, the loss of power from the off-site electric power system.

Criterion 28 - Inspection and testing of electric power systems

The safety-related electric power systems are designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components. The systems are designed with a capability to test periodically:

1) the operability and functional performance of the components of the systems, such as on-site power sources, relays, switches, and buses; and
2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among the on-site and off-site power supplies.

Table 3.1-3 – SHINE Design Criteria
(Sheet 9 of 11)

Confinement and Control of Radioactivity Design Criteria

Criterion 29 - Confinement design

Confinement boundaries are provided to establish a low-leakage barrier against the uncontrolled release of radioactivity to the environment and to assure that confinement design leakage rates are not exceeded for as long as postulated accident conditions require. Four classes of confinement boundaries are established:

1) the primary confinement boundary,
2) the process confinement boundary,
3) hot cells and gloveboxes, and
4) radiologically-controlled area ventilation isolations

Criterion 30 - Confinement design basis

Each confinement boundary is designed to withstand the conditions generated during postulated accidents.

Criterion 31 - Fracture prevention of confinement boundary

Each confinement boundary design reflects consideration of service temperatures and other conditions of the confinement boundary material during operation, maintenance, testing, and postulated accident conditions to prevent fracture of the confinement boundary.

Criterion 32 - Provisions for confinement testing and inspection

Each confinement boundary is designed to permit:

1) appropriate periodic inspection of important areas, such as penetrations;
2) an appropriate surveillance program; and
3) periodic testing of confinement leakage rates.

Table 3.1-3 – SHINE Design Criteria
(Sheet 10 of 11)

Criterion 33 - Piping systems penetrating confinement Piping systems penetrating confinement boundaries that have the potential for excessive leakage are provided with isolation capabilities appropriate to the potential for excessive leakage. Piping systems that pass between confinement boundaries are equipped with either: 1) a locked closed manual isolation valve, or 2) an automatic isolation valve that takes the position that provides greater safety upon loss of actuating power. Manual isolation valves are maintained locked-shut for any conditions requiring confinement boundary integrity.
Criterion 34 - Confinement isolation Lines from outside confinement that penetrate the primary confinement boundary and are connected directly to the primary system boundary are provided with redundant isolation capabilities. Ventilation, monitoring, and other systems that penetrate the primary, process, glovebox or hot cell confinement boundaries, are connected directly to the confinement atmosphere and are not normally locked closed, have redundant isolation capabilities or are otherwise directed to structures, systems, and components capable of handling any leakage. Isolation valves outside confinement boundaries are located as close to the confinement as practical and upon loss of actuating power, automatic isolation valves are designed to take the position that provides greater safety. Manual isolation valves are maintained locked-shut for any conditions requiring confinement boundary integrity. All electrical connections from equipment external to the confinement boundaries are sealed to minimize air leakage.
Criterion 35 - Control of releases of radioactive materials to the environment The facility is designed to include means to suitably control the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal operation, including anticipated transients. Sufficient holdup capacity is provided for retention of radioactive gases.

Table 3.1-3 – SHINE Design Criteria
(Sheet 11 of 11)

Criterion 36 -Target solution storage and handling and radioactivity control The target solution storage and handling, radioactive waste, and other systems that contain radioactivity are designed to assure adequate safety under normal and postulated accident conditions. These systems are designed with: 1) capability to permit appropriate periodic inspection and testing of safety-related components, 2) suitable shielding for radiation protection, 3) appropriate confinement and filtering systems, and 4) residual heat removal capability having reliability and testability that reflects the importance of decay heat and other residual heat removal.
Criterion 37 - Criticality control in the radioisotope production facility Criticality in the radioisotope production facility is prevented by physical systems or processes and the use of administrative controls. Use of geometrically safe configurations is preferred. Control of criticality adheres to the double contingency principle. A criticality accident alarm system to detect and alert facility personnel of an inadvertent criticality is provided.
Criterion 38 - Monitoring radioactivity releases Means are provided for monitoring the primary confinement boundary, hot cell, and glovebox atmospheres to detect potential leakage of gaseous or other airborne radioactive material. Potential effluent discharge paths and the plant environs are monitored for radioactivity that may be released from normal operations, including anticipated transients, and from postulated accidents.
Criterion 39 - Hydrogen mitigation Systems to control the buildup of hydrogen that is released into the primary system boundary and tanks or other volumes that contain fission products and produce significant quantities of hydrogen are provided to ensure that the integrity of the system and confinement boundaries are maintained.

3.2 METEOROLOGICAL DAMAGE

3.2.1 WIND LOADING

This subsection discusses the criteria used to design the SHINE facility for protection from wind loading conditions.

3.2.1.1 Applicable Design Parameters

The SHINE facility structure is designed to withstand wind pressures based on a basic wind velocity of 90 miles per hour (mph) (145 kilometers per hour [kph]) adjusted for a mean recurrence interval of 100 years, per Figure 6-1 and Table C6-7 of American Society of Civil Engineers/Structural Engineering Institute (ASCE), Standard 7-05, Minimum Design Loads for Buildings and Other Structures (ASCE, 2006).

3.2.1.2 Determination of Applied Forces

The design wind velocity is converted to velocity pressure in accordance with Equation 6-15 of ASCE 7-05 (ASCE, 2006):

$$q_z = 0.00256K_zK_{zt}K_dV^2I \text{ (pounds per square foot [lb/ft}^2\text{])} \qquad \text{(Equation 3.2-1)}$$

Where:

K_z = velocity pressure exposure coefficient evaluated at height (z) in Table 6-3 of ASCE 7-05

K_{zt} = topographic factor as defined in Section 6.5.7 of ASCE 7-05

K_d = wind directionality factor in Table 6-4 of ASCE 7-05

V = basic wind speed (3-second gust) obtained from Figure 6-1 of ASCE 7-05 for Wisconsin

I = importance factor = 1.15

The design wind pressures and forces for the building at various heights above ground are obtained in accordance with Section 6.5.12.2.1 of ASCE 7-05 (ASCE, 2006) by multiplying the velocity pressure by the appropriate pressure coefficients, gust factors, accounting for sloped surfaces (i.e., the roof of the building). The building is categorized as an enclosed building according to Section 6.2 of ASCE 7-05 (ASCE, 2006) and, as a result, both external and internal pressures are applied to the structure. A positive and negative internal pressure is applied to the internal surfaces of the exterior walls as well as the roof.

3.2.2 TORNADO LOADING

This subsection discusses the criteria used to design the SHINE facility to withstand the effects of a design-basis tornado phenomenon.

3.2.2.1 Applicable Design Parameters

The design-basis tornado characteristics are described in Regulatory Guide 1.76, Design Basis Tornado for Nuclear Power Plants (USNRC, 2007a):

a. Design-basis tornado characteristics are listed in Table 1 of Regulatory Guide 1.76 for Region I.
b. The design-basis tornado missile spectrum and maximum horizontal missile speeds are given in Table 2 of Regulatory Guide 1.76.

3.2.2.2 Determination of Applied Forces

The maximum tornado wind speed is converted to velocity pressure in accordance with Equation 6-15 of ASCE 7-05 (ASCE, 2006):

$$q_z = 0.00256 K_z K_{zt} K_d V^2 I \text{ (lb/ft}^2\text{)} \quad \text{(Equation 3.2-2)}$$

Where:

K_z = velocity pressure exposure coefficient equal to 0.87

K_{zt} = topographic factor equal to 1.0

K_d = wind directionality factor equal to 1.0

V = maximum tornado wind speed equal to 230 mph (370 kph) for Region I

I = importance factor equal to 1.15

The tornado differential pressure is defined in Regulatory Guide 1.76, Table 1 as 1.2 pounds per square inch (psi) (8.3 kilopascals [kPa]) for Region I (USNRC, 2007a). The tornado differential pressure is applied as an outward pressure to the exterior walls of the building, as well as the roof, because the structure is categorized as an enclosed building in accordance with Section 6.2 of ASCE 7-05 (ASCE, 2006).

The procedure used for transforming the tornado-generated missile impact into an effective or equivalent static load on the structure is consistent with NUREG-0800, Standard Review Plan for the Review of Safety Analysis for Nuclear Power Plants (SRP) Section 3.5.2, Subsection II (USNRC, 2007b).

The loading combinations of the individual tornado loading components and the load factors are in accordance with SRP Section 3.3.2 (USNRC, 2007c).

3.2.2.3 Effect of Failure of Structures, Systems, or Components Not Designed for Tornado Loads

SSCs whose failure during a tornado event could affect the safety-related portions of the facility are either designed to resist the tornado loading or the effect on the safety-related structures from the failure of these SSCs or portions thereof are shown to be bounded by the tornado missile or aircraft impact evaluations.

The Seismic Category I boundary provides missile walls to protect safety-related systems from damage due to tornado missiles. SSCs that are credited to prevent or mitigate potential accidents caused by a tornado event are protected by the design of the enclosed structure. The structural analysis does not credit venting of the Seismic Category I boundary during a tornado event. The differential pressure on all surfaces as an enclosed structure results in higher pressures, and the differential pressure would be reduced by the effects of venting. Therefore, there are no consequences to venting the building during a tornado event.

3.2.3 SNOW, ICE, AND RAIN LOADING

This subsection discusses the criteria used to design the SHINE facility to withstand conditions due to snow, ice, and rain loading. Rain loading is not considered in the structural design of the building as the sloped roofs do not result in rain accumulation. As a result of the lack of rain accumulation, load due to ice is anticipated to be minimal and is enveloped by the design snow load.

3.2.3.1 Applicable Design Parameters

Snow load design parameters pertinent to the SHINE facility are provided in Chapter 7 of ASCE 7-05 (ASCE, 2006).

3.2.3.2 Determination of Applied Forces

The sloped roof snow load is calculated in accordance with Sections 7.3 and 7.4 of ASCE 7-05 (ASCE, 2006). The combined equation utilized to calculate the sloped roof load is:

$$p_s = 0.7C_sC_eC_tIp_g \qquad \text{(Equation 3.2-3)}$$

Where:

C_s = roof slope factor as determined by Sections 7.4.1 through 7.4.4 of ASCE 7-05

C_e = exposure factor as determined by Table 7-2 of ASCE 7-05

C_t = thermal factor as determined by Table 7-3 of ASCE 7-05

I = importance factor as determined by Table 7-4 of ASCE 7-05

p_g = ground snow load as set forth in Figure 7-1 of ASCE 7-05

Unbalanced roof snow loads are computed in accordance with Section 7.6 of ASCE 7-05 (ASCE, 2006). The design snow drift surcharge loads are computed in accordance with Section 7.7.1 of ASCE 7-05 (ASCE, 2006).

3.3 WATER DAMAGE

The design basis precipitation, flood levels, and ground water levels for the SHINE facility are as follows:

- Design basis flood level: 50 feet (ft.) (15.2 meters [m]) below grade.
- Design basis precipitation level: at grade.
- Maximum ground water level: 50 ft. (15.2 m) below grade.

Per Subsection 2.4.2.3, a local probable maximum precipitation (PMP) event creates a water level about level with grade. The first floor of the building is at least 4 inches (in.) (10.2 centimeters [cm]) above grade; therefore, water will not infiltrate the door openings in the case of a local PMP event.

Per Subsection 2.4.3, a local probable maximum flood (PMF) event creates a water level approximately 50 ft. (15.2 m) below grade. The water elevation for the PMF is derived from FEMA flood profiles. The lowest point of the facility is 26 ft. (7.9 m) below grade; therefore, flooding does not cause any structural loading in the case of a local PMF event.

The impact of internal flooding is determined by the maximum flow rate and the volume of water available to feed the flood. No active response is assumed to terminate the flow and the entire volume of available water is assumed to spill into the SHINE facility. For water sources outside the building (fire water), automatic or operator actions are required to terminate the flow.

Berms and ramps are used within the facility to:

- Capture and contain water collected in the RCA resulting from postulated water system ruptures or fire system discharges above grade.
- Prevent water intrusion into the uranium receipt and storage system (URSS) and target solution preparation system (TSPS) rooms.
- Prevent a release of water from the RCA due to the postulated failure of the radioisotope process chilled water system (RPCS) room, the process chilled water system (PCHS), or the facility demineralized water system (FDWS).
- Prevent bulk release of water into the radioactive drain system (RDS) sump tanks thereby overfilling the sump collection piping.

Safety-related equipment vulnerable to water damage is protected by locating it in flood-protective compartments and/or installing it above flood elevation.

3.3.1 FLOOD PROTECTION

This subsection discusses the flood protection measures that are applicable to safety-related SSCs for both external flooding and postulated flooding from failures of facility components containing liquid.

Analyses of the worst flooding due to pipe and tank failures and their consequences are performed in this subsection.

3.3.1.1 Flood Protection Measures for Structures, Systems, and Components

Postulated flooding from component failures in the building compartments is prevented from adversely affecting plant safety or posing any hazard to the public. Exterior or access openings and penetrations into the SHINE facility are above the maximum postulated flooding level and thus do not require protection against flooding.

3.3.1.1.1 Flood Protection from External Sources

Safety-related components located below the design (PMP) flood level are protected using the hardened protection approach described below. The safety-related systems and components are flood-protected because they are enclosed in a reinforced concrete safety-related structure, which has the following features:

a. Exterior walls below flood level are not less than 2 ft. (0.61 m) thick.
b. Water stops are provided in construction joints below flood level.
c. Waterproofing is applied to external surfaces exposed to flood level.
d. Roofs are designed to prevent pooling of large amounts of water.

Waterproofing of foundations and walls of Seismic Category I structures below grade is accomplished principally by the use of water stops at construction joints.

In addition to water stops, waterproofing of the SHINE facility is provided up to 4 in. (10.2 cm) above the plant ground level to protect the external surfaces from exposure to water.

There is no fire protection piping in the RCA general area.

3.3.1.1.2 Flood Protection from Internal Sources

The total discharge from the fire protection discharge consists of the combined volume from any firefighting hoses. In accordance with National Fire Protection Association (NFPA) 801, Section 5.10 (NFPA, 2008), the credible volume of discharge is sized for a manual fire-fighting flow rate of 500 gallons per minute (1893 liters per minute) for a duration of 30 minutes (min.). Therefore, the total discharge volume is 15,000 gallons (56,782 liters). The resulting flooded water depth in the RCA from fire protection discharge is less than 2 in. This bounds the total water available in the PCHS and RPCS cooling systems that could cause internal flooding.

The floors of the URSS/TSPS rooms are elevated to prevent water intrusion in the event of an internal flood. Water sensitive safety-related equipment is raised from the floor 8 in. (20.3 cm) in the RCA to provide defense in depth. Therefore, the depth of water due to fire protection discharge is less than the elevation that water sensitive safety-related equipment is raised from the floor.

Outside of the RCA there is limited water discharge from fire protection systems. The safety-related function(s) of systems that are subject to the effects of a discharge of the fire suppression system are appropriately protected by redundancy and separation. The uninterruptible electrical power supply system (UPSS) has two trains to provide redundancy. These trains are isolated from each other to prevent one train from being damaged by discharge of the fire protection system in the vicinity of the other train. Any water sensitive safety-related equipment is installed a minimum of 8 in. (20.3 cm) above the floor slab at grade.

Flood scenarios have been considered for the pipe trenches and vaults. Process piping, vessels, and tanks containing special nuclear material (SNM) or radioactive liquids are seismically qualified. There is no high-energy piping within these areas. Any pipe or tank rupture in the radioisotope production facility (RPF) vaults is routed to the radioactive drain system (RDS). The RDS is sized for the maximum postulated pipe or tank failure as described in Subsection 9b.7.6. The design of the shield plugs over the pipe trenches and vaults prevents bulk leakage of liquid into the vaults from postulated flooding events within the remainder of the RCA.

The light water pool in the irradiation unit cell (IU) is filled to an elevation approximately equal to the top of the surrounding area floor slab. Given the robust design of the light water pool (approximately 4 ft. thick reinforced concrete) and the stainless steel liner, loss of a significant amount of pool water is not credible.

3.3.1.2 Permanent Dewatering System

There is no permanent dewatering system provided for the flood design.

3.3.2 STRUCTURAL DESIGN FOR FLOODING

Since the design PMP elevation is at the finished plant grade and the PMF elevation is approximately 50 ft. (15.2 m) below grade, there is no dynamic force due to precipitation or flooding.

The load from build-up of water due to discharge of fire water in the RCA is supported by slabs on grade, with the exception of the mezzanine floor. Openings that are provided in the mezzanine ensure that the mezzanine slab is not significantly loaded. The mezzanine floor slab is designed to a live load of 250 pounds per square foot (1221 kilograms per square meter). Therefore, the mezzanine floor slab is capable of withstanding temporary water collection that may occur while water is draining from the mezzanine floor.

3.4 SEISMIC DAMAGE

Seismic analysis criteria for the SHINE facility conform to IAEA-TECDOC-1347, Consideration of External Events in the Design of Nuclear Facilities other than Nuclear Power Plants, with Emphasis on Earthquakes (IAEA, 2003), which provides generic requirements and guidance for the seismic design of nuclear facilities other than nuclear power plants. Additional criteria provided in the Regulatory Guides and NUREG-0800, Standard Review Plan for the Review of Safety Analysis for Nuclear Power Plants (SRP), provide more detailed guidance in the seismic analysis of the main production facility structure (FSTR).

The dimensions of the FSTR at grade level are approximately 212 feet (ft.) (64.6 meters [m]) in the north-south (N/S) direction and 158 ft. (48.2 m) in the east-west (E/W) direction. The main production facility is a single-story building with a mezzanine, with a roof height of approximately 58 ft. (17.7 m). The FSTR also includes an exhaust stack with a height of approximately 67 ft. (20.4 m). The SHINE facility main floor has below grade reinforced concrete vaults for housing equipment. The roof of the facility is supported by a steel truss system.

The FSTR building is a box-type shear wall system of reinforced concrete. The major structural elements include the foundation mat, mezzanine floor, roof slab supported by roof trusses, and shear walls. The exterior building walls of the majority of the FSTR are thick cast-in-place concrete, and are designed to protect the people, materials, and equipment inside the facility from natural and manmade accidents.

The FSTR includes the irradiation facility (IF), the radioisotope production facility (RPF), the non-radiologically controlled seismic area, and a nonsafety-related area. The IF contains the irradiation units (IUs) and tritium purification system (TPS), and the RPF contains the supercell and below-grade tanks. The non-radiologically controlled seismic area contains the control room, battery rooms, uninterruptible electrical power supply rooms, and other miscellaneous support rooms. The RPF, IF, and non-radiologically controlled seismic area are within the seismic boundary and are classified as Seismic Category I. These areas contain the safety-related structures, systems, and components (SSCs). To the south of the seismic boundary are the shipping and receiving areas, as well as other areas that contain nonsafety-related support systems and equipment. This part of the structure is not Seismic Category I. The areas outside the seismic boundary do not contain safety-related SSCs.

The FSTR is modeled to the analyses described in this chapter. The concrete walls, slabs, and basemat are modeled using thick shell elements. The steel structural members are modeled using three-dimensional beam elements. Seismic mass is considered in the model in accordance with SRP Section 3.7.2 (USNRC, 2013a). Figure 3.4-1 and Figure 3.4-2 provide three-dimensional views of the structural model.

Certain material in this section provides information that is used in the technical specifications, including conditions for operation and design features. In addition, significant material is also applicable to, and may be referenced by, the bases that are described in the technical specifications.

3.4.1 SEISMIC INPUT

3.4.1.1 Design Response Spectra

The safe shutdown earthquake (SSE) ground motion is defined with a maximum ground acceleration of 0.2 g and design response spectra in accordance with Regulatory Guide 1.60, Revision 2, Design Response Spectra for Seismic Design of Nuclear Power Plants (USNRC, 2014a).

Consistent with SRP Section 3.7.2 (USNRC, 2013a), the location of the ground motion should be at the ground surface. The competent material (material with a minimum shear wave velocity of 1,000 feet per second [ft./sec] [305 meters per second {m/s}]) is 7.5 ft. (2.3 m) below the ground surface for the site. Hence, the SSE response spectra are defined as an outcrop at a depth of 7.5 ft. (2.3 m) below grade.

3.4.1.2 Design Time Histories

For soil-structure interaction (SSI) analysis and for generating in-structure response spectra, design acceleration time histories are required. Synthetic acceleration time histories are generated to envelop the design response spectra. Mutually orthogonal synthetic acceleration time histories are generated for each horizontal direction and one for the vertical direction. Each of these time histories meets the design response spectra enveloping requirements consistent with Approach 2, Option 1 of SRP Section 3.7.1 (USNRC, 2014b). The specifics of each of these time histories are:

- Each synthetic time history has been generated starting with seed recorded earthquake time histories.
- The strong motion durations (Arias intensity to rise from 5 percent to 75 percent) of synthetic time histories are greater than a minimum of 6 seconds.
- The time history has a sufficiently small increment and sufficiently long duration. Records shall have a Nyquist frequency of at least 50 hertz (Hz) and a total duration of at least 20 seconds. The time step increment will be 0.005 seconds, which meets the Nyquist requirement for frequencies up to 100 Hz.
- Spectral acceleration at 5 percent damping is computed at a minimum of 100 points per frequency decade, uniformly spaced over the log frequency scale from 0.1 Hz to 50 Hz or the Nyquist frequency.
- Comparison of the response spectrum obtained from the synthetic time history with the target response spectrum shall be made at each frequency computed in the frequency range of interest.
- The computed 5 percent damped response spectrum of the acceleration time history shall not fall more than 10 percent below the target response spectrum at any one frequency and shall have no more than 9 adjacent frequency points falling below the target response spectrum.
- The computed 5 percent damped response spectrum of the artificial time history shall not exceed the target spectrum at any frequency by more than 30 percent in the frequency range of interest.

3.4.1.3 Critical Damping Values

Structural damping values for various structural elements used in the seismic analyses are provided in Section 1.1 of Regulatory Guide 1.61, Revision 1, Damping Values for Seismic Design of Nuclear Power Plants (USNRC, 2007d). In the modal analysis, for structures composed of different materials (having different damping values) the composite modal damping is calculated using either the stiffness-weighted method or mass-weighted method, based on SRP Section 3.7.2 (USNRC, 2013a). This applies to either the response spectrum method or the time history method.

3.4.2 SEISMIC ANALYSIS OF FACILITY STRUCTURES

3.4.2.1 Seismic Analysis Methods

The general equation of motion (as seen below) is used regardless of the method selected for the seismic analysis.

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=-[M]\{\ddot{u}_g\} \qquad \text{(Equation 3.4-1)}$$

Where:

[M]	=	mass matrix
[C]	=	damping matrix
[K]	=	stiffness matrix
$\{\ddot{x}\}$	=	column vector of relative accelerations
$\{\dot{x}\}$	=	column vector of relative velocities
$\{x\}$	=	column vector of relative displacements
$\{\ddot{u}_g\}$	=	ground acceleration

Analytical models are represented by finite element models. Consistent with SRP Section 3.7.2 (USNRC, 2013a), SRP Acceptance Criterion 3.C, finite element models are acceptable if the following guidelines are met:

- The type of finite element used for modeling a structural system should depend on structural details, the purpose of analysis, and the theoretical formulation upon which the element is based. The mathematical discretization of the structure should consider the effect of element size, shape, and aspect ratio on solution accuracy.
- In developing a finite element model for dynamic response, it is necessary to consider that local regions of the structure, such as individual floor slabs or walls, may have fundamental vibration modes that can be excited by the dynamic seismic loading. These local vibration modes are represented in the dynamic response model, in order to ensure that the in-structure response spectra include the additional amplification.

The finite element model consists of plate/shell, solid, beam, or a combination of finite elements.

3.4.2.2 Soil-Structure Interaction (SSI) Analysis

The SSI model provides structural responses for design basis level seismic loading of the SHINE facility, including transfer functions, maximum seismic acceleration (zero period acceleration [ZPA]), and in-structure response spectra (ISRS) (horizontal and vertical directions) for various damping values. The SSI model is developed using the computer program Structural Analysis Software System Interface (SASSI2010), version 1.0.

Major structural elements of the SHINE facility, including walls, slabs, beams and columns, are modeled with appropriate mass and stiffness properties. Major openings within walls and slabs are included in the SSI model. The model uses thick shell elements to represent concrete slabs and walls, and beam elements to represent steel members, mostly comprising the truss components in the facility. Elements are modeled at the geometric centerline of the structural member they represent with the following exceptions:

- The below grade and mezzanine slabs are modeled at their actual top-of-slab elevation.
- Minor adjustments are made to the dimensions and locations of wall openings to maximize mesh regularity in the model.
- Roof truss locations are adjusted to align with the roof shell element mesh.

In addition to self-weight of the structure, floor loads and equipment loads are converted to mass and included in the model. A portion of the loads are considered mass sources in the following manner according to SRP Section 3.7.2 (USNRC, 2013a):

- Dead Load ………………100 percent
- Live Load…………………25 percent
- Snow Load……………….75 percent

In addition to the loads that are converted to mass, the hydrodynamic mass of the water in the IU cells is included.

The SSI analyses are performed separately on an equivalent linear-elastic basis for mean (best estimate [BE]), upper bound (UB), and lower bound (LB) soil properties to represent potential variations in in-situ and backfill soil conditions around the building in accordance with SRP Section 3.7.2 (USNRC, 2013a). SSI analysis requires detailed input of the soil layers supporting the structure. Strain dependent soil properties were determined from geotechnical investigations and free field site response analysis. The free-field site response analysis is performed for the LB, BE, and UB soil properties. In accordance with SRP Section 3.7.2, the UB and LB values of the soil shear modulus, *G,* are obtained in terms of their BE through the equations shown below. Equations 3.4-2 and 3.4-3 are used to calculate the low strain properties for the LB and UB. The final soil properties are calculated from the SHAKE2000 program, version 3.5.

$$G_{LB} = \frac{G_{BE}}{(1 + COV)} \quad \text{(Equation 3.4-2)}$$

$$G_{UB} = G_{BE}(1 + COV) \quad \text{(Equation 3.4-3)}$$

Where, *COV* is the coefficient of variation. A COV of 0.5 is used because the site is well-investigated.

3.4.2.3 Combination of Earthquake Components

In order to account for the responses of the structures subjected to the three directional (two horizontal and the vertical) excitations, the maximum co-directional responses are combined using either the square root of the sum of the squares (SRSS) method or the 100-40-40 rule as described in Section 2.1 of Regulatory Guide 1.92, Revision 3, Combining Modal Responses and Spatial Components in Seismic Response Analysis (USNRC, 2012).

3.4.2.4 Seismic Analysis Results

The seismic loads are applied to the structural analysis model as described in Subsection 3.4.2.6 and utilized to develop in-structure response spectra of the facility for use in sizing equipment and components. Response spectra accelerations are output from SASSI at the 75 standard frequencies between 0.2 Hz and 34 Hz as suggested by Regulatory Guide 1.122, Revision 1, Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components (USNRC, 1978). In addition, response spectra accelerations are specified to be output at frequencies of 37 Hz, 40 Hz, 43 Hz, 46 Hz and 50Hz.

3.4.2.5 Assessment of Structural Seismic Stability

The stability of the SHINE facility is evaluated for sliding and overturning considering the following load combinations and factors of safety in accordance with Section 7.2 of American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) Standard 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities (ASCE/SEI, 2005) and SRP Section 3.8.5 (USNRC, 2013b):

Load Combination	Minimum Factor of Safety: Sliding	Minimum Factor of Safety: Overturning	
$D + H + E'$	1.1	1.1	(Equation 3.4-4)
$D + H + W_t$	1.1	1.1	(Equation 3.4-5)
$D + H + W$	1.5	1.5	(Equation 3.4-6)

Where:

D = Dead Load

H = Lateral Earth Pressures

E' = Earthquake Load

W_t = Tornado Load

W = Wind Load

The base reactions due to seismic forces envelop the reactions due to wind and tornado loading; therefore, a stability analysis for wind and tornado is not required. Seismic excitation in each direction is considered using the 100-40-40 percent combination rule as specified in Subsection 3.4.2.3 above.

The lateral driving forces applicable to the seismic stability evaluation of the SHINE facility include active lateral soil force, static surcharge lateral soil force, dynamic surcharge lateral soil, dynamic lateral soil force, and seismic lateral inertial force. The resistance for sliding is due to the static friction at the soil-basemat interface for sliding evaluation and passive lateral soil resistance. The self-weight of the structure is considered in the resistance to overturning effects.

3.4.2.6 Structural Analysis of Facility

3.4.2.6.1 Description of the Structures

The SHINE facility is a box-type shear wall system of reinforced concrete with reinforced concrete floor slabs. The major structural elements in the SHINE facility include the shear walls, the floor and roof slabs, and the foundation mat.

3.4.2.6.2 Applicable Codes and Standards

- ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary (ACI, 2014)
- ANSI/AISC N690-12, Specification for Safety-Related Steel Structures for Nuclear Facilities (ANSI/AISC, 2012)

3.4.2.6.3 Site Design Parameters

The following subsections provide the site-specific parameters for the design of the facility.

3.4.2.6.3.1 Soil Parameters

The soil parameters for the facility are provided below.

- Net allowable static bearing pressure at 3 ft. below grade: 2380 pounds per square foot (psf) (114 kilopascal [kPa]).
- Net allowable static bearing pressure at 17 ft. below grade: 1230 psf (58.9 kPa).
- Minimum average shear wave velocity: 459 ft./sec (140 m/s).
- Minimum unit weight: 117 pounds per cubic foot (lb/ft^3) (1874 kilograms per cubic meters [kg/m^3]).

3.4.2.6.3.2 Maximum Ground Water Level

- 50 ft. (15.2 m) below grade level.

3.4.2.6.3.3 Maximum Flood Level

- Section 2.4 describes the probable maximum precipitation (PMP).
- Section 2.4 describes the probable maximum flood (PMF).

3.4.2.6.3.4 Snow Load

- Snow load: 30 psf (1.44 kPa) (50-year recurrence interval).
- A factor of 1.22 is used to account for the 100-year recurrence interval required.

3.4.2.6.3.5 Design Temperatures

- The winter dry-bulb temperature (-7°F [-22°C]).
- The summer dry bulb temperature (88°F [31°C]).

3.4.2.6.3.6 Seismology

- SSE peak ground acceleration (PGA): 0.20 g (for both horizontal and vertical directions).
- SSE response spectra: per Regulatory Guide 1.60 (USNRC, 2014a).
- SSE time history: envelope SSE response spectra in accordance with SRP Section 3.7.1 (USNRC, 2014b).

3.4.2.6.3.7 Extreme Wind

- Basic wind speed for Wisconsin: 90 miles per hour (mph) (145 kilometers per hour [kph]) (50-year recurrence interval).
- A factor of 1.07 is used to account for the 100-year recurrence interval required.
- Exposure Category C.

3.4.2.6.3.8 Tornado

- Maximum tornado wind speed (Region 1): 230 mph (370 kph).
- Radius of maximum rotational speed: 150 ft. (45.7 m).
- Tornado differential pressure: 1.2 pounds per square inch (psi) (8.3 kPa).
- Missile Spectrum: see Table 2 of Regulatory Guide 1.76 (USNRC, 2007a).

3.4.2.6.3.9 Rainfall

- The SHINE facility's sloped roof and building configuration preclude accumulation of rainwater; therefore, rain loads are not considered in this evaluation.

3.4.2.6.4 Design Loads and Loading Combinations

3.4.2.6.4.1 Dead Load

Dead loads consist of the weight of all materials of construction incorporated into the building, as well as the following:

- Concrete cover blocks for below grade tanks and trenches.
- Fixed equipment (includes tanks and hot cells).
- Partition walls.
- Precast tank vaults in the RPF.
- Weight of commodities attached to structural elements.
- Crane dead loads as described in Subsection 3.4.2.6.4.6.

3.4.2.6.4.2 Live Load

The building is evaluated for live loads consistent with the use of and occupancy of the facility. This includes minimum live loads driven by occupancy and non-permanent loads caused by equipment or required during plant operations.

The following categories encompass the live loads for the SHINE facility:

- A distributed live load of 125 psf (5.99 kPa) is used for areas designated as light manufacturing.
- A distributed live load of 250 psf (12.0 kPa) is used for areas designated as heavy manufacturing.

Additionally, the following categories are considered as live loads in the areas where they occur:

- Concrete cover block laydown load.
- Supercell drum export system and shield gate live load.
- Forklift live load associated with the movement of a shipping container throughout the radiologically controlled area (RCA).
- Roof live load.
- Equipment live loading.

3.4.2.6.4.3 Snow Load

The snow load is based on a ground snow load of 30 psf (1.44 kPa) with an importance factor of 1.2 and a mean recurrence interval of 100 years.

3.4.2.6.4.4 Wind Load

The wind load is based on a basic wind speed of 90 mph (145 kph) with an importance factor of 1.15 and a mean recurrence interval of 100 years.

3.4.2.6.4.5 Earthquake Load

Dynamic analysis is conducted with a portion of the loads considered as mass sources in the following manner according to SRP Section 3.7.2 (USNRC, 2013a):

- Dead Load ………………100 percent
- Live Load…………………25 percent
- Snow Load……………….75 percent
- Parked Crane Load…….100 percent
- Hydrodynamic Load……100 percent

Earthquake load is applied in a SAP2000 model (version 17.2) on an equivalent static basis. The equivalent static model represents the soil as dynamic springs, developed in accordance with ASCE 4-98 (ASCE, 2000). Maximum seismic acceleration at each node of the structure is determined by SSI analysis using SASSI2010, as discussed in Subsection 3.4.2.2. Figures 3.4-3 through 3.4-6 show selected response spectra locations throughout the FSTR.

The SAP2000 and SASSI2010 models are both three-dimensional models that represent the structural elements with equivalent mass and stiffness properties. The lumped masses at each node of the SAP2000 analysis are multiplied by the peak accelerations determined from the SSI analysis to determine an equivalent static earthquake load at each node. The direction of load application is iterated to obtain nine seismic force terms.

3.4.2.6.4.6 Crane Load

The building is evaluated for loads associated with two overhead bridge cranes, one servicing the IU cell area and one servicing the RPF area. Crane loading is evaluated in accordance with American Society for Mechanical Engineers (ASME) NOG-1, Rules for Construction of Overhead and Gantry Cranes (ASME, 2004).

3.4.2.6.4.7 Soil Pressure

Sub-grade walls of the SHINE facility are designed to resist static lateral earth pressure loads, compaction loads, static earth pressure, dynamic surcharge loads, and elastic dynamic soil pressure loads. Static earth pressure consists of at-rest, active, and passive soil pressure loads, which are applied as required to ensure the stability of the building.

3.4.2.6.4.8 Fluid Load

The hydrostatic loading is calculated based on the actual dimensions of the IU cells and applied in the model as lateral hydrostatic pressure on the walls and vertical hydrostatic pressure on the bottom slabs.

3.4.2.6.4.9 Tornado Load

The tornado load is based on a tornado wind speed of 230 mph (370 kph) and a tornado missile spectrum as described in Table 2 of Regulatory Guide 1.76 (USNRC, 2007a). The tornado load, W_t, is further defined by the following combinations:

$$W_t = W_p \qquad \text{(Equation 3.4-7)}$$

$$W_t = W_w + 0.5W_p \qquad \text{(Equation 3.4-8)}$$

$$W_t = W_w + 0.5W_p + W_m \qquad \text{(Equation 3.4-9)}$$

Where:

W_p = load from tornado atmospheric pressure change

W_w = load from tornado wind

W_m = load from tornado missile impact

3.4.2.6.4.10 Accidental Eccentricity

As required by Section 3.1.1(e) of ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary (ASCE, 2000), the structure is evaluated for a torsional moment due to accidental eccentricity. The torsional moment is taken equal to the story shear at the elevation and in the direction of interest times a moment arm equal to 5 percent of the building dimension. The torsional moment is distributed to the building shear walls based on the relative rigidity of the walls in plane. The loads are applied statically and account for variability in the load direction.

3.4.2.6.5 Structural Analysis Model

A three-dimensional finite element model of the SHINE facility structure was created using the computer program SAP2000 (version 17.2) to represent the mass and stiffness of the major structural elements, equipment, and components of the FSTR. The model utilizes shell elements to represent slabs and walls, and frame elements to represent columns and beams. Elements are modeled at the geometric centerline of the structural member they represent with the following exceptions:

- The below grade and mezzanine slabs are modeled at their actual top-of-slab elevation.
- Minor adjustments are made to the dimensions and locations of wall openings to maximize mesh regularity in the model.
- Roof truss locations are adjusted to align with the roof shell element mesh.

The adjustments described above are intended to maintain mesh regularity to the extent possible.

3.4.2.6.6 Structural Analysis Results

Concrete walls and slabs in the SHINE facility are designed for axial, flexural, and shear loads per provisions of ACI 349-13 (ACI, 2014) considering all applicable design basis load combinations. Walls and slabs are modeled in SAP2000 using shell elements. To determine the longitudinal and transverse reinforcement required within a wall or slab, the design is performed on an element basis. Using resultant forces obtained from SAP2000 model data, the element is designed as a reinforced concrete section per ACI 349-13 (ACI, 2014). The required area of steel is determined for combined axial and flexural loads, in-plane shear loads, and out-of-plane shear loads. Using these results, reinforcement size and spacing is specified.

3.4.3 SEISMIC CLASSIFICATION AND QUALIFICATION

This subsection discusses the methods by which the SHINE facility SSCs are classified and qualified to ensure functional integrity.

3.4.3.1 Seismic Classification

Facility SSCs, including their foundations and supports, that must perform safety function(s) after an SSE are designated as Seismic Category I. Safety-related SSCs are classified as Seismic Category I.

SSCs that are co-located with a Seismic Category I SSC and must maintain structural integrity in the event of an SSE to prevent unacceptable interactions with a Seismic Category I SSC, but are not required to remain functional, are designated as Seismic Category II.

The seismic classifications of SSCs are shown in Table 3.4-1.

3.4.3.2 Seismic Qualification

In general, one of the following four methods of seismically qualifying the SSCs is chosen based upon the characteristics and complexities of the subsystem:

- Dynamic analysis.
- Testing.
- Comparison with existing databases.
- A combination of analysis and testing.

The methods to be used for qualification are stated below. These methods will depend on the type of equipment and supporting structure. The following defines some of the possible cases and associated analytical methods which may be used in each case.

ISRS for the FSTR are used to determine the appropriate seismic design of equipment, piping, and components in the safety-related envelope. For the evaluation of cable and conduit raceway systems, quantitative evaluation criteria are applied only to the most seismically vulnerable portions of these systems.

3.4.3.2.1 Qualification by Analytical Methods

Analytical calculations may be used as a qualification method when maintaining the structural integrity is an assurance for the safety function. This method can be used for equipment and piping systems when expected response to the earthquake excitations can be characterized as linear or simple non-linear behavior (e.g., piping, skids, and large equipment).

ISRS from Subsection 3.4.2.2 are used in the response spectrum analysis of piping and equipment. These response spectra are used to determine the seismic requirements at the component mounting locations for qualification purposes and for piping subsystem dynamic analysis.

<u>Static Analysis</u>

The equipment, as well as its support, can be considered rigid, and may be analyzed by static analysis, if it can be shown that its fundamental natural frequency does not fall in the frequency range below the high frequency asymptote (ZPA) of the required response spectrum (RRS).

For rigid equipment supported by a rigid structure, the equipment motion shall be the same as the floor motion without amplification. The horizontal and vertical dynamic accelerations shall be taken as the ZPA from the applicable response spectrum. These acceleration values are used to perform a static analysis. In this case, the dynamic forces are determined by multiplying the mass of the subassembly or parts of the equipment by the ZPA of the RRS. These forces should be applied through the center of gravity of the subassembly or the part of the equipment.

The stresses resulting from each force (in each of the three directions) should be combined by an appropriate combination method to yield the dynamic stresses. The dynamic deflections (deflections due to dynamic loads) may be calculated in the same manner. These dynamic stresses and deflections are combined with stresses and deflections from other loads per the load combinations defined in the applicable design codes.

Simplified Dynamic Analysis

A simplified dynamic analysis may be performed in cases where the equipment and support systems' natural frequency falls in the frequency range below the high frequency asymptote (ZPA) of the applicable RRS. This is similar to the static analysis described above but requires using different values for the accelerations. The accelerations to be used are obtained from the appropriate ISRS curves at each natural frequency in the frequency range of interest. If the frequency information is not available, the simplified dynamic analysis (sometimes referred to as the equivalent static analysis) is performed using 1.5 times the maximum peak of the applicable floor response spectra. Once the dynamic forces are determined using the 1.5 times the peak acceleration values from the RRS, stresses and deformations may be computed following the same procedures used for static analysis.

Detailed Dynamic Analysis

When acceptable justification for static or simplified dynamic analysis cannot be provided, a detailed dynamic analysis is performed. A mathematical model may be constructed to represent the dynamic behavior of the equipment. A finite element model may be constructed and analyzed using the response spectrum modal analysis or time-history analysis. The maximum inertia forces, at each mass point, from each mode, are applied at that point to calculate the modal reactions (forces and moments) and modal deformations (translations and rotations). The various modal contributions are combined by an appropriate combination method. Closely spaced modes are combined by using an approach from Regulatory Guide 1.92 (USNRC, 2012). The stresses and deflections resulting from each of the three directions are combined to obtain the dynamic stresses and deflections. These dynamic stresses and deflections are combined with stresses and deflections from other loads per the load combinations defined in the applicable design codes.

3.4.3.2.2 Qualification by Tests

Seismic qualification by testing is the preferred method of qualification for complex equipment not suitable for analysis, and for equipment required to perform an active function (e.g., valves and instrumentation). Qualification by testing may be performed using applicable procedures specified by Institute of Electrical and Electronics Engineers (IEEE) and/or ASME qualification of active mechanical equipment (QME) standards.

The vibration inputs for the seismic tests are the response spectra or Required Input Motion (typical for line-mounted equipment) at the mounting location of the equipment. ISRS are used to develop Test Response Spectra for testing.

The test samples shall be mounted to simulate the recommended service mounting. If this cannot be done, the effect of the actual supporting structure shall be considered in determination of the input motion. The project specification will state the expected (or calculated) piping nozzle reaction loads on the equipment which shall be used in the qualification. Any other loads that may act on the component (mechanical, electrical, or instrument) during the postulated dynamic event must be simulated during the test, unless the supporting test (or calculations) shows that they are insignificant.

At the completion of the tests, inspection shall be made by the test conductor to assure that no structural damage has occurred. Sufficient monitoring devices shall be used to evaluate the performance of the active components during the tests. For acceptability, the components shall demonstrate their ability to perform their intended safety functions when subjected to all applicable loads.

3.4.3.2.3 Comparison with Existing Databases

ISRS are used to develop RRS for comparison with existing response from a database. The candidate equipment must be similar to equipment in the existing seismic experience databases.

3.4.3.2.4 Combined Methods of Qualification

Based on the available information, component complexity, and functional requirements, the above mentioned analytical and test methods may be combined in various sequence and content to achieve seismic qualification of the subject components.

3.4.4 SEISMIC INSTRUMENTATION

Seismic instrumentation is not required under Section IV(a)(4) of Appendix S to 10 CFR 50 or Section VI(a)(3) of Appendix A to 10 CFR 100 because the SHINE facility is not a nuclear power plant. However, the facility has nonsafety-related seismic instrumentation to record accelerations experienced at the site during a seismic event.

The seismic instrumentation establishes the acceptability of continued operation of the plant following a seismic event. This system provides acceleration time histories or response spectra experienced at the facility to assist in verifying that safety-related SSCs at the SHINE facility can continue to perform their safety functions.

Seismic monitoring is performed by the process integrated control system (PICS), which is described in Section 7.3. Indication of a seismic event results in an alarm in the facility control room.

3.4.5 SEISMIC ENVELOPE DESIGN FOR EXTERNAL HAZARDS

3.4.5.1 AIRCRAFT IMPACT ANALYSIS

The safety-related structures at the SHINE facility are evaluated for aircraft impact loading resulting from small aircraft which frequent the Southern Wisconsin Regional Airport (SWRA). The analysis consists of a global impact response analysis and a local impact response analysis.

The global impact response analysis is performed using the energy balance method, consistent with U.S. Department of Energy (DOE) Standard DOE-STD-3014-2006 (DOE, 2006). The permissible ductility limit for reinforced concrete elements is in accordance with Appendix F of ACI 349-13 (ACI, 2014). The permissible ductility limit for truss members is determined from Chapter NB of ANSI/AISC N690-12 (ANSI/AISC, 2012). The calculated values are then used to create the appropriate elastic or elastic-plastic load deflection curves. From these curves, the available energy absorption capacity of the structure at the critical impact locations is determined. The Challenger 605 was selected as the critical aircraft for the global impact analysis based on a study of the airport operations data. The Challenger 605 is evaluated as a design basis aircraft impact. The probabilistic distributions of horizontal and vertical velocity of impact are determined from Attachment E of Lawrence Livermore National

Laboratory UCRL-ID-123577 (UCRL, 1997) to correspond to 99.5 percent of impact velocity probability distribution.

Each wall that protects safety-related equipment was evaluated for impacts at the center of the wall panel and at critical locations near the edge of the wall panel. Each roof that protects safety-related equipment was evaluated for impacts near the end of the roof truss, at the center of the roof truss, at the center of the roof panel between trusses.

The local response evaluation was conducted using empirical equations in accordance with DOE-STD-3014-2006 (DOE, 2006). The structure was shown to resist scabbing and perforation. A punching shear failure was not postulated based on Appendix F of ACI 349-13 (ACI, 2014). Scabbing and perforation thickness requirement was calculated using DOE-STD-3014-2006 (DOE, 2006).

Because engine diameter and engine weight are both critical for the local evaluation, the local impact evaluation was performed for the Hawker 400 as well as the Challenger 605 aircraft. The Challenger 605 and Hawker 400 are evaluated as design basis aircraft impacts.

To evaluate the capability of the structure to withstand impact from an aircraft, each wall that is subject to potential impact from an aircraft missile is evaluated. Figure 3.4-7 shows the openings in the building which are evaluated as missile barriers.

The design basis aircraft impacts have been evaluated against the acceptance criteria of ACI 349-13 (ACI, 2014) for concrete and ANSI/AISC N690-12 (ANSI/AISC, 2012) for steel and it has been demonstrated that all components of the FSTR structure that are relied upon to provide impact protection have adequate energy absorption capacity to perform their design basis function.

3.4.5.2 EXPLOSION HAZARDS

Because the SHINE facility is not licensed as an operating nuclear reactor, explosions postulated as a result of the design basis threat as defined in Regulatory Guide 5.69, Guidance for the Application of Radiological Sabotage Design-Basis Threat in the Design, Development and Implementation of a Physical Security Program that Meets 10 CFR 73.55 Requirements (USNRC, 2007e), are not considered. However, accidental explosions due to transportation or storage of hazardous materials outside the facility and accidental explosions due to chemical reactions inside the facility are assessed in the integrated safety analysis.

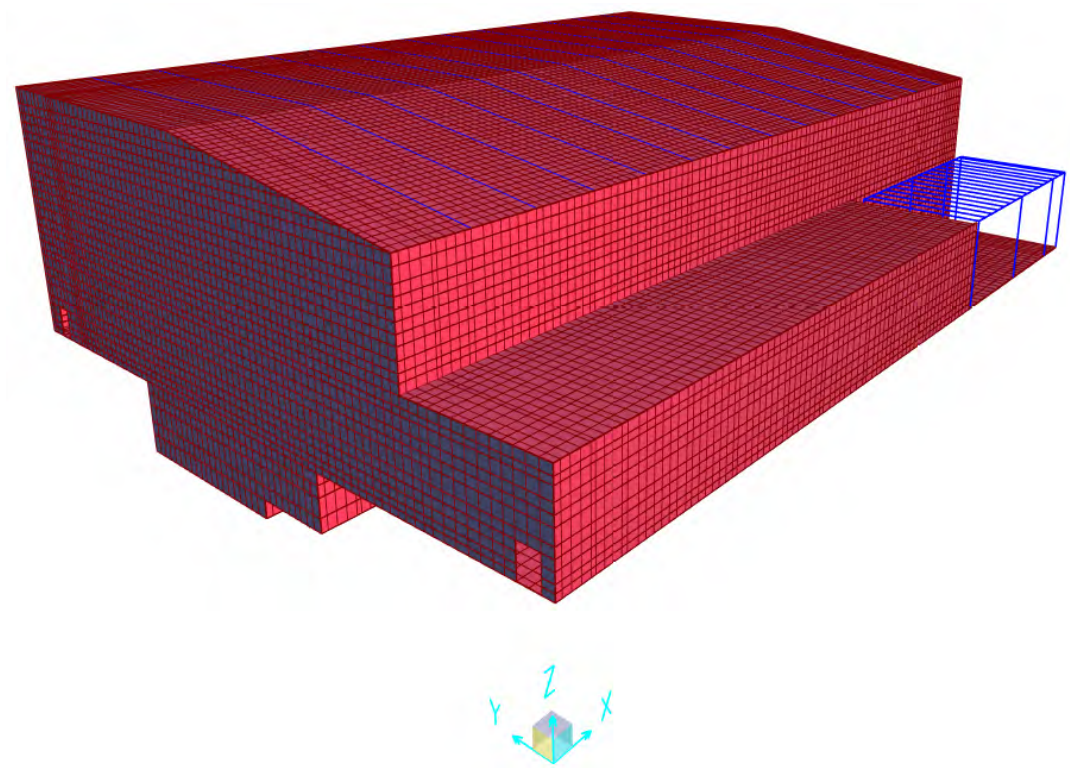
The maximum overpressure at any safety-related area of the facility from any credible external source is discussed in Subsection 2.2.3). The seismic area is protected by outer walls and roofs consisting of reinforced concrete robust enough to withstand credible external explosions as defined in Regulatory Guide 1.91, Revision 2, Evaluations of Explosions Postulated to Occur at Nearby Facilities and on Transportation Routes Near Nuclear Power Plants (USNRC, 2013c).

Table 3.4-1 – Seismic Classification of Structures, Systems, and Components

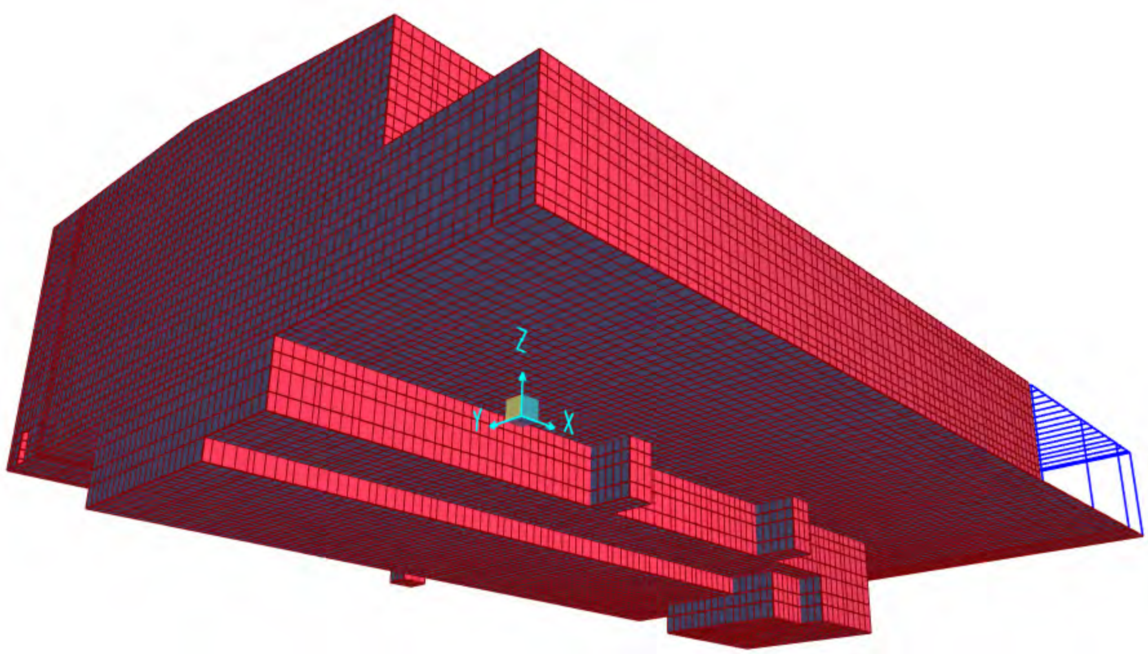
System, Structure, and Component	Acronym	Seismic Category
Engineered safety features actuation system	ESFAS	I
Facility fire detection and suppression system	FFPS	II
Facility structure	FSTR	I
Iodine and xenon purification and packaging	IXP	I
Irradiation cell biological shield	ICBS	I
Light water pool system	LWPS	I
Material handling system	MHS	II
Molybdenum extraction and purification system	MEPS	I
Neutron driver assembly system	NDAS	II
Neutron flux detection system	NFDS	I
Nitrogen purge system	N2PS	I
Normal electrical power supply system	NPSS	I
Primary closed loop cooling system	PCLS	I
Process vessel vent system	PVVS	I
Production facility biological shield	PFBS	I
Radioactive drain system	RDS	I
Radioactive liquid waste immobilization	RLWI	I
Radioactive liquid waste storage	RLWS	I
Radiological ventilation zone 1	RVZ1	I
Radiological ventilation zone 2	RVZ2	I
Radiological ventilation zone 3	RVZ3	I
Subcritical assembly system	SCAS	I
Target solution preparation system	TSPS	I
Target solution staging system	TSSS	I
Tritium purification system	TPS	I
Target solution vessel (TSV) off-gas system	TOGS	I
TSV reactivity protection system	TRPS	I
Uninterruptible electrical power supply system	UPSS	I
Uranium receipt and storage system	URSS	I
Vacuum transfer system	VTS	I

Note: The seismic category listed is the highest for the system. Portions of the system may have a lower seismic categorization.

Figure 3.4-1 – View Looking Southwest of the Representative Concrete Sections



Full structure (looking southeast)



Full structure from below El. 0 ft. (looking southeast)

Figure 3.4-2 – Cross Section of Structural Model

Figure 3.4-3 – Selected Response Spectra, Exterior Locations (Looking Southeast)

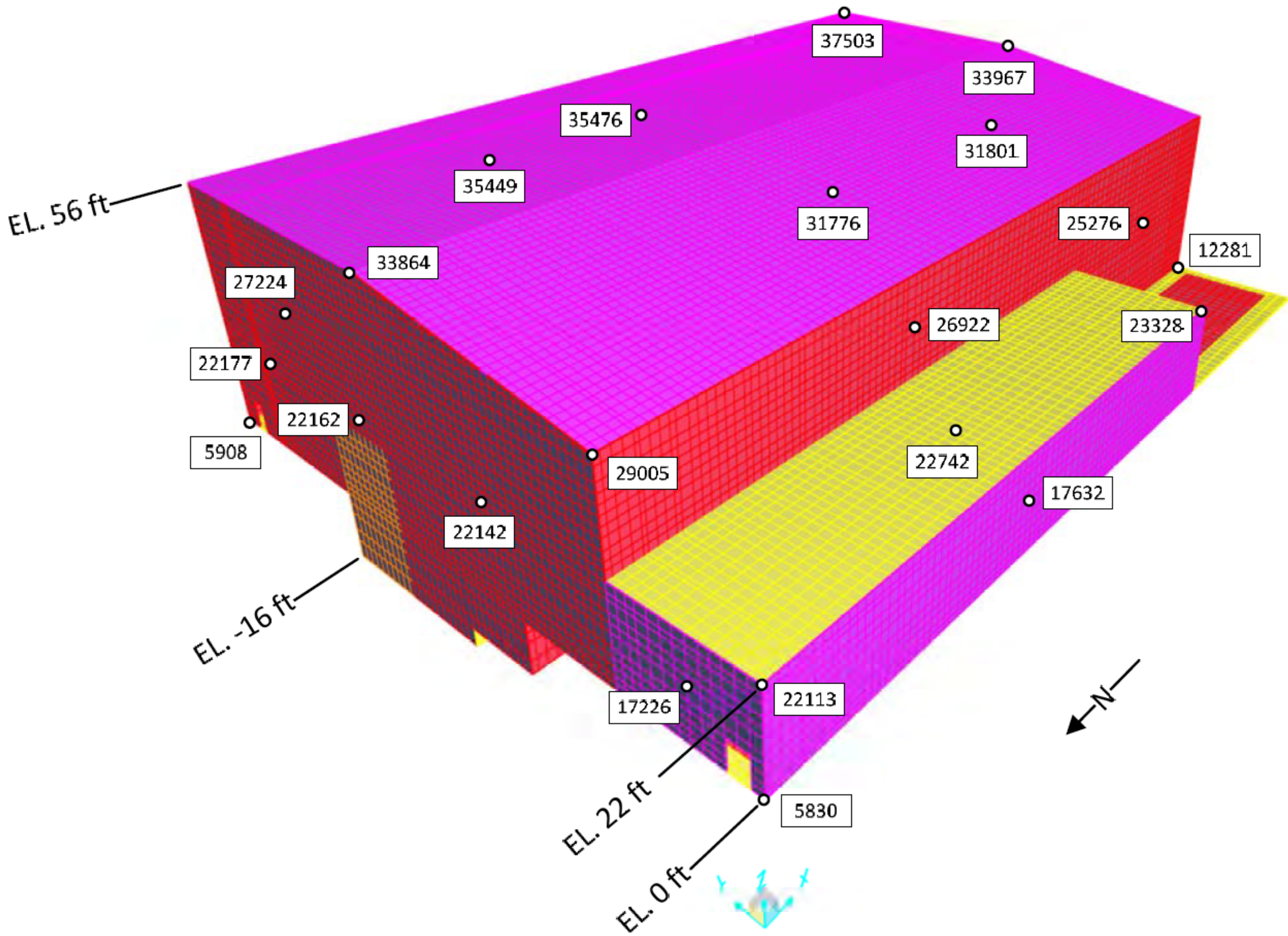


Figure 3.4-4 – Selected Response Spectra, Exterior Locations (Looking Northwest)

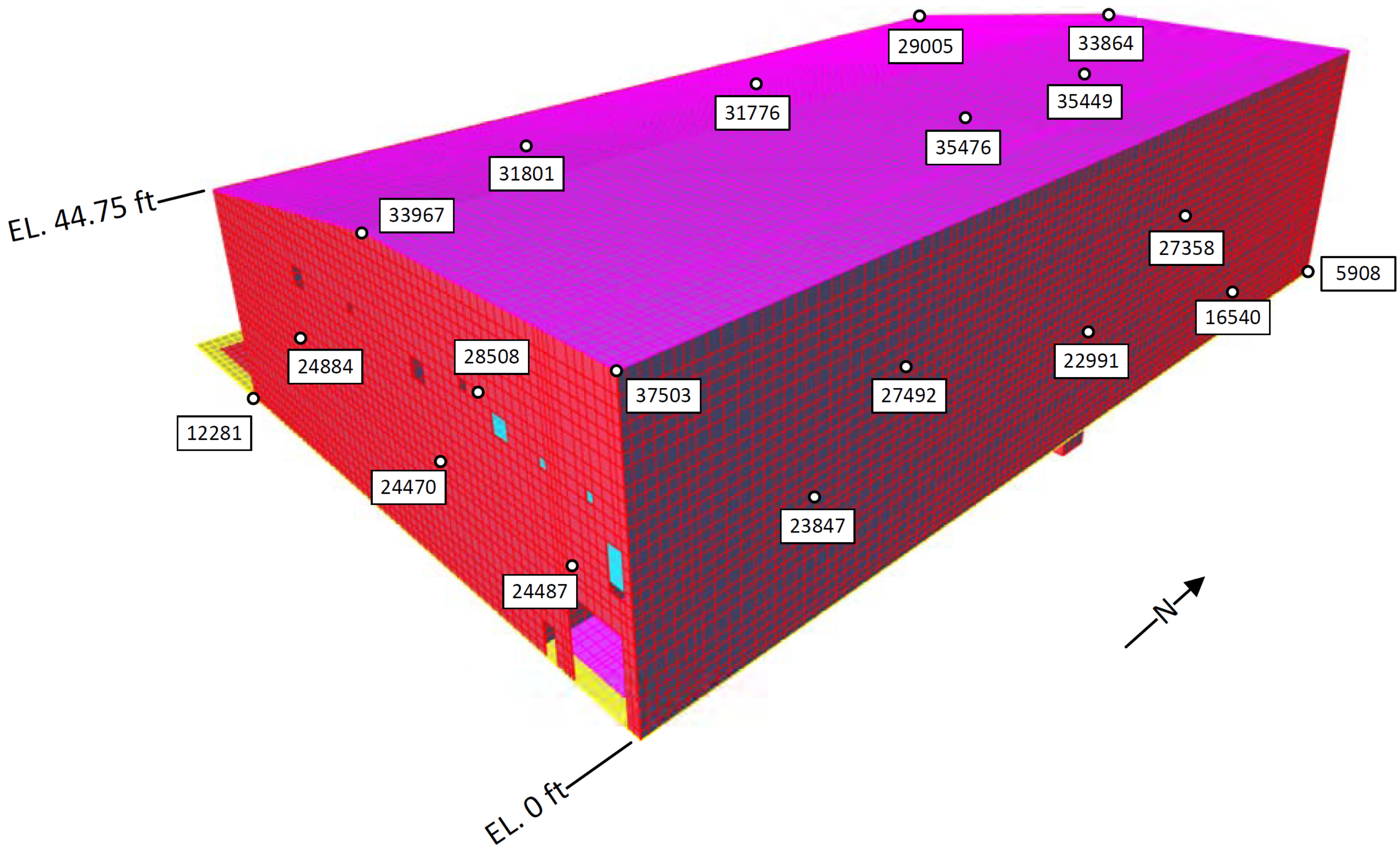
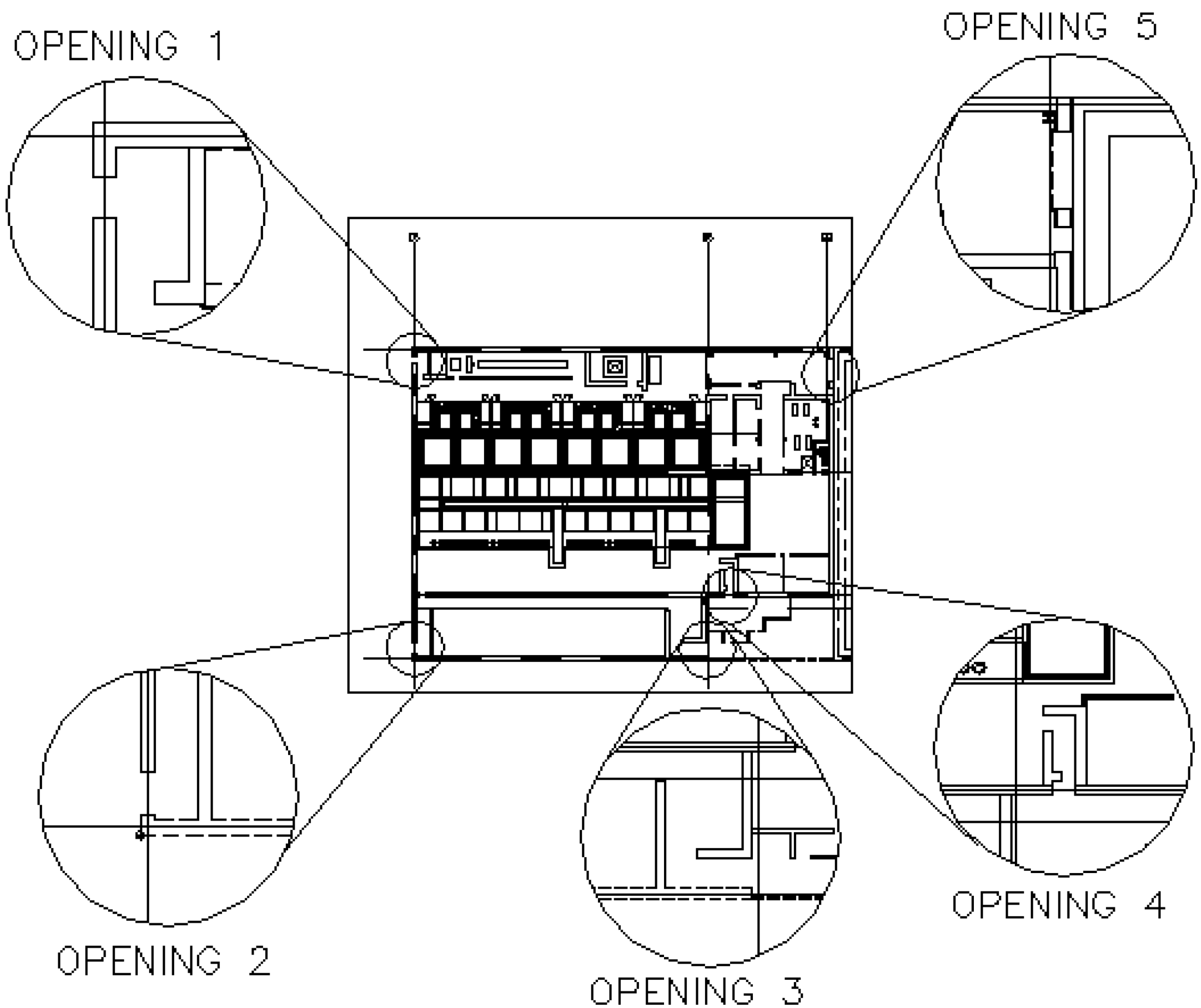


Figure 3.4-5 – Selected Response Spectra Locations At Grade Slab

Figure 3.4-6 – Selected Response Spectra Locations Below Grade Slab

Figure 3.4-7 – Building Envelope Openings Evaluated as Missile Barriers



3.5 SYSTEMS AND COMPONENTS

The SHINE facility structure, system, and component (SSC) designs are based on the SHINE design criteria described in Section 3.1.

The design of the SHINE facility and systems is based on defense-in-depth practices. Defense-in-depth practices means 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 upon 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 greater tolerance to failures and external challenges.

The SHINE facility and system design incorporates a preference for engineered controls over administrative controls, independence to avoid common mode failures, and incorporates other features that enhance safety by reducing challenges to safety-related components and systems.

Physical separation and electrical isolation are used to maintain the independence of safety-related control circuits and equipment among redundant safety divisions or with nonsafety systems so that the safety functions required during and following design basis events can be accomplished.

Redundancy is also incorporated into system designs. Two divisions of safety-related protection systems and two divisions of safety-related emergency power are provided for active engineered controls that depend on control and/or continued power to perform their safety functions. Active engineered safety-related SSCs requiring control or power may be reduced to a single division when redundancy of the function is provided by other means (e.g., when a check valve is used in combination with an automatically actuated isolation valve).

The design bases for the SSCs of the SHINE facility are described in detail throughout the FSAR. The FSAR sections where SSCs are described also provide information that is used in the technical specifications. This includes limiting conditions for operation, setpoints, design features, and means for accomplishing surveillances. In addition, these FSAR sections also present information that is applicable to, and may be referenced by, the technical specification bases.

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