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Advanced Reactor Integrated Energy System - Thermal Energy Storage Island Design

September 2023

Rami M. Saeed, Terry Morton

Idaho National Laboratory

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Idaho National Laboratory
Integrated Energy Systems
Idaho Falls, Idaho 83415

http://www.ies.inl.gov

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ACRONYMS

AR	advanced reactor
DOME	Demonstration of Microreactor Experiments
IES	integrated energy system
INL	Idaho National Laboratory
MFC	Materials and Fuel Complex
NPP	nuclear power plant
NRIC	National Reactor Innovation Center
TES	thermal energy storage

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Advanced Reactor Integrated Energy System - Thermal Energy Storage Island Design

1 INTRODUCTION

In the rapidly evolving landscape of energy supply and distribution, flexibility has become a prized attribute, surpassing the traditional notions of stability and baseload generation capability. This shift in priorities is particularly evident in regard to nuclear power plants (NPPs), for which adaptability is becoming more important than the ability to generate a constant output. As we rethink our energy infrastructure and resources so as to embrace the rise of distributed energy generation, the inherent variability in net demand continues to expand. Moreover, use of nuclear energy as a source of heat for decarbonizing the industrial sector is becoming a very pressing topic. It is in this context that advanced NPPs have become poised to enter a more competitive energy market, delivering both flexible electricity and heat. This shift is motivating the exploration of thermal energy storage (TES) systems to empower NPPs by imparting nimble responsiveness to market fluctuations, flexible heat delivery capabilities, and a redefined role in the energy field. TES systems offer the unique advantage of storing nuclear energy, in its original form, as heat, thus affording unparalleled flexibility in terms of its subsequent utilization.

2 BACKGROUND

The main topic of this research is integrated energy systems (IES) designed for pairing industrial thermal energy loads with advanced reactors (ARs). The Idaho National Laboratory (INL) Crosscutting Technology Development IES program and the National Reactor Innovation Center (NRIC) are seeking to develop, design, and construct an AR-IES demonstration platform that couples the thermal output from an AR operating at the INL/NRIC Demonstration of Microreactor Experiments (DOME) test bed in the Experimental Breeder II dome to a variable capacity load emulator (i.e., air-cooled radiator) and sensible TES via a molten salt thermal energy transfer fluid. Though a two-tank TES system was selected as the representative storage technology for demonstrating the use of TES within an integrated system, it should not be interpreted as being the primary storage option for all AR-IES.

1.1 Demonstration Site

INL is a unique asset within the Department of Energy complex, being a facility with a long history of developing and demonstrating various types of low-power reactors. The facilities located within INL reactor sites operate inside mature nuclear safety bases and are manned by qualified nuclear operations staff. One such facility under development is the INL/NRIC DOME test bed in the Experimental Breeder II dome, located within the Materials and Fuel Complex (MFC). The DOME project aims to modify MFC-767, MFC-768, and the surrounding area to create a test bed that supports the demonstration and operation of Ars currently being designed for operation at MFC. MFC-767 is an ideal AR location, as it formerly housed a similar-sized reactor. Such attributes, along with the available space and ongoing design development, well equip the DOME Project to effectively coordinate with the AR-IES Project in designing, constructing, and operating in a manner consistent with established nuclear safety processes/protocols.

The AR-IES demonstrates the transfer of reactor thermal energy generated at a constant rate and temperature, as well as energy storage for users needing thermal energy at variable rates and/or different temperatures.

1.2 Thermal Energy Storage Overview

TES technologies enable the accumulation and release of energy through the heating of a heat transfer medium in storage medium. When integrated with nuclear systems, TES systems store excess thermal energy that can later be harnessed for power generation during periods of high demand—thus improving NPP efficiency and grid synchronization—and can serve as a buffer and management solution in transferring heat to industrial processes. The TES technology chosen for this project (i.e., the two-tank molten-salt system) is cost-effective and compatible with both existing and future nuclear systems, due to its flexible temperature operating range. This technology incorporates two separate storage tanks and can be classified into direct and indirect heating setups. The molten salts that serve as the heat transfer fluids afford stability, low costs, and increased safety. This approach shows promise in regard to optimizing energy management in both nuclear and renewable energy applications. Figure 1 shows an example of a typical two-tank molten-salt system coupled to a NPP.

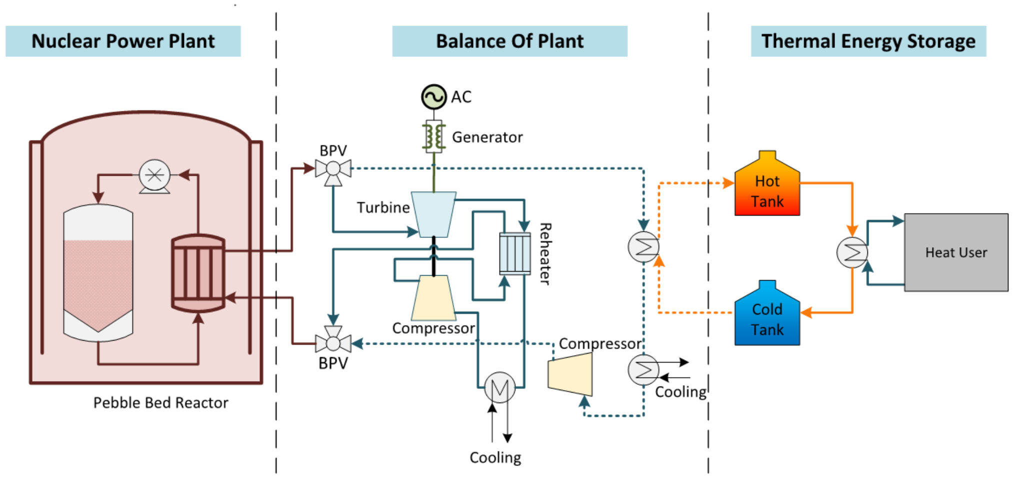


Figure 1. Example of a TES system coupled to a NPP.

3 AR-IES System Description

This section provides an overview of the envisioned system shown in Figure 2 through Figure 4. A more detailed description is provided in the Appendix.

Allocated Space: It was proposed that the platform be located within 10–200 ft of the DOME site (exact location to be determined), on a transportable skid.

Charge-Side Heat Exchanger: One heat exchanger (gas-to-molten-salt heat exchange), with gas from DOME (as the reactor is being tested in DOME) being circulated through the IES charge heat exchanger.

TES System: Two sets of TES tanks, one set to store cold salt and the other to store hot salt. Each of the two cold and hot tank sets will include one to four tanks.

Piping and Pumps: For drawing molten salt from the TES tanks, then pushing it through the platform heat exchangers and back around to the TES tanks.

Discharge-Side Controllable Load: The discharge side of the TES tanks is connected to a variable/controllable heat load emulator that rejects heat to the atmosphere via an air-cooled radiator or chiller plant.

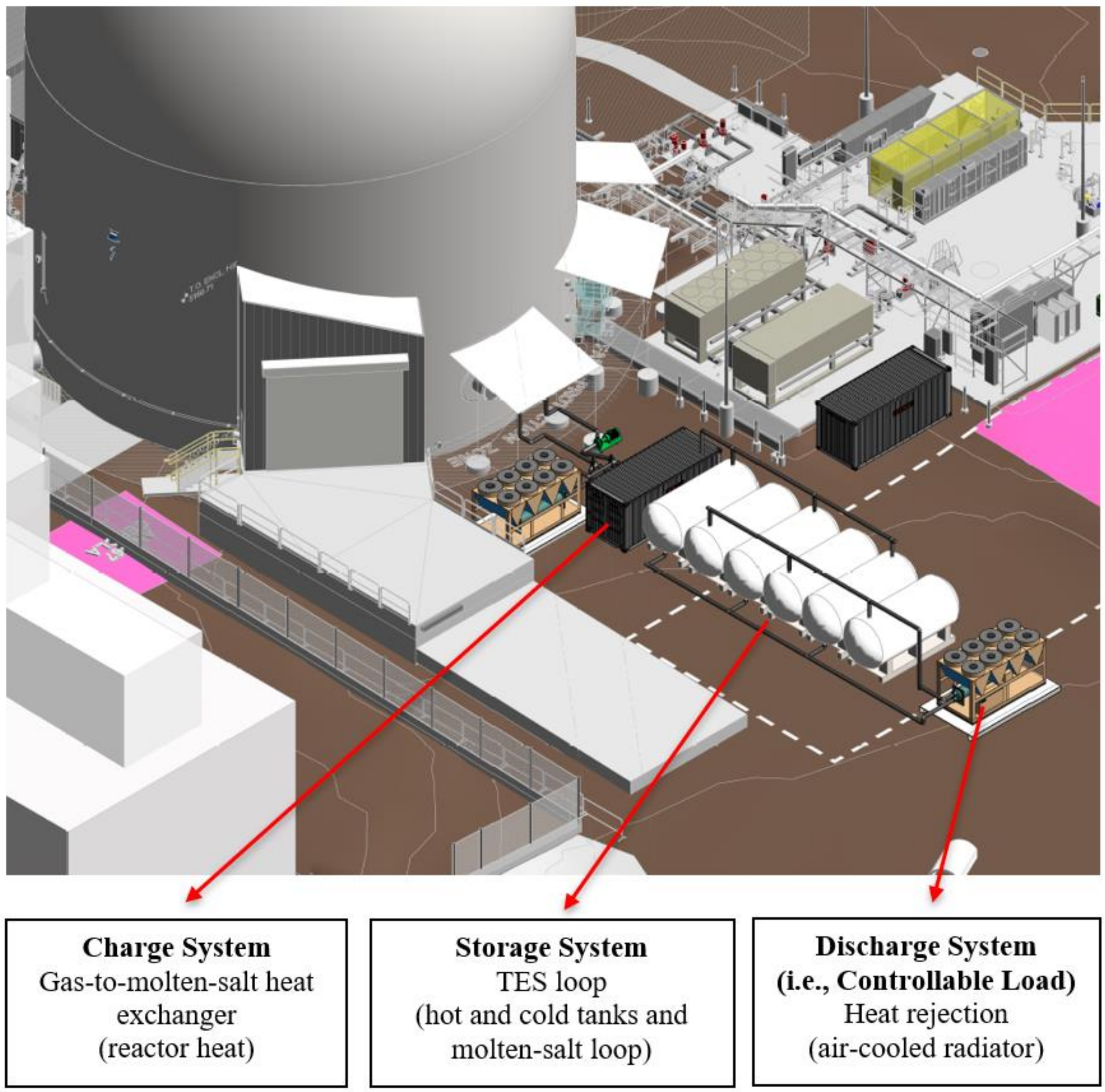


Figure 2. 3-D schematic of the envisioned AR-IES island.

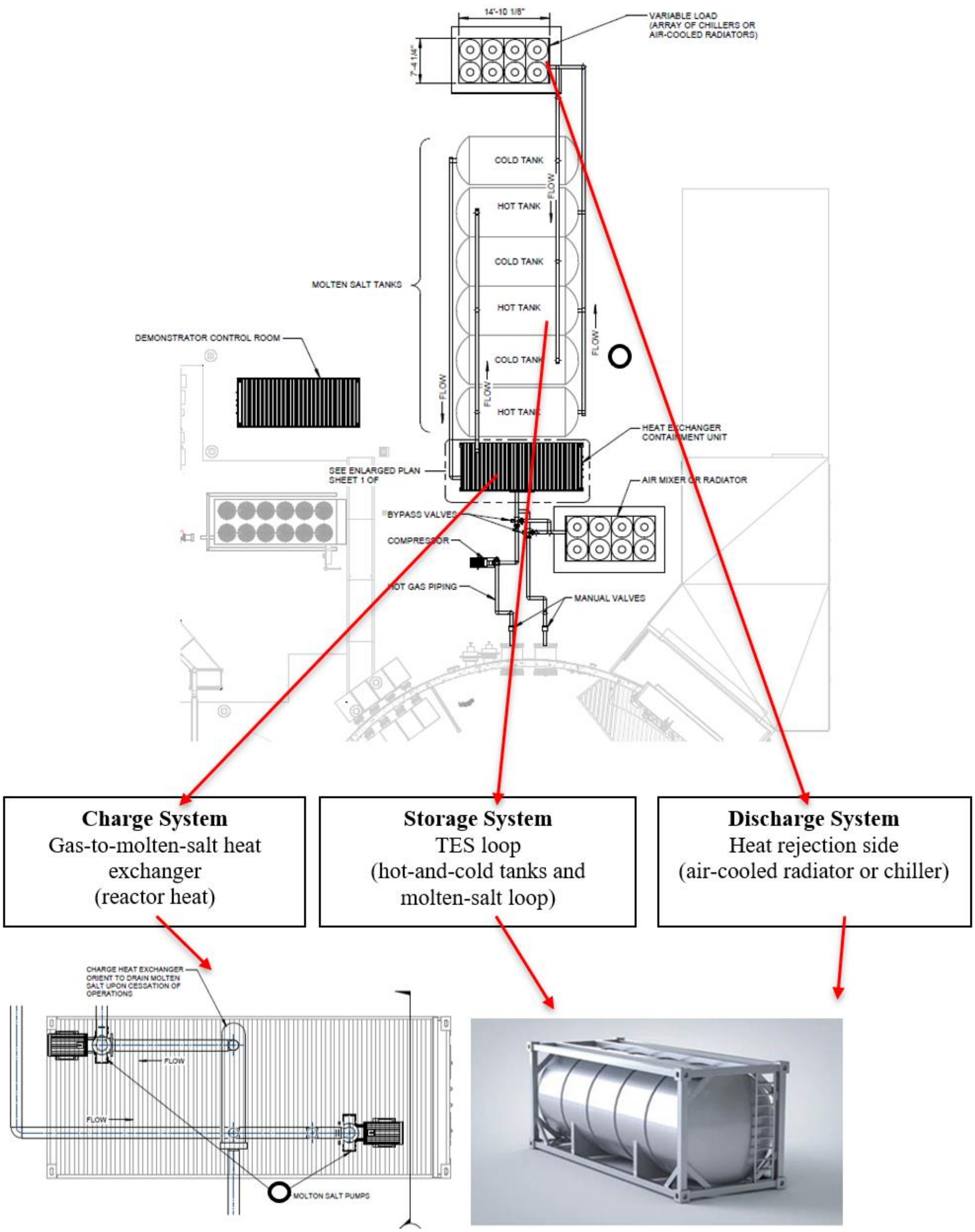


Figure 3. 2-D sketch of the envisioned AR-IES island.

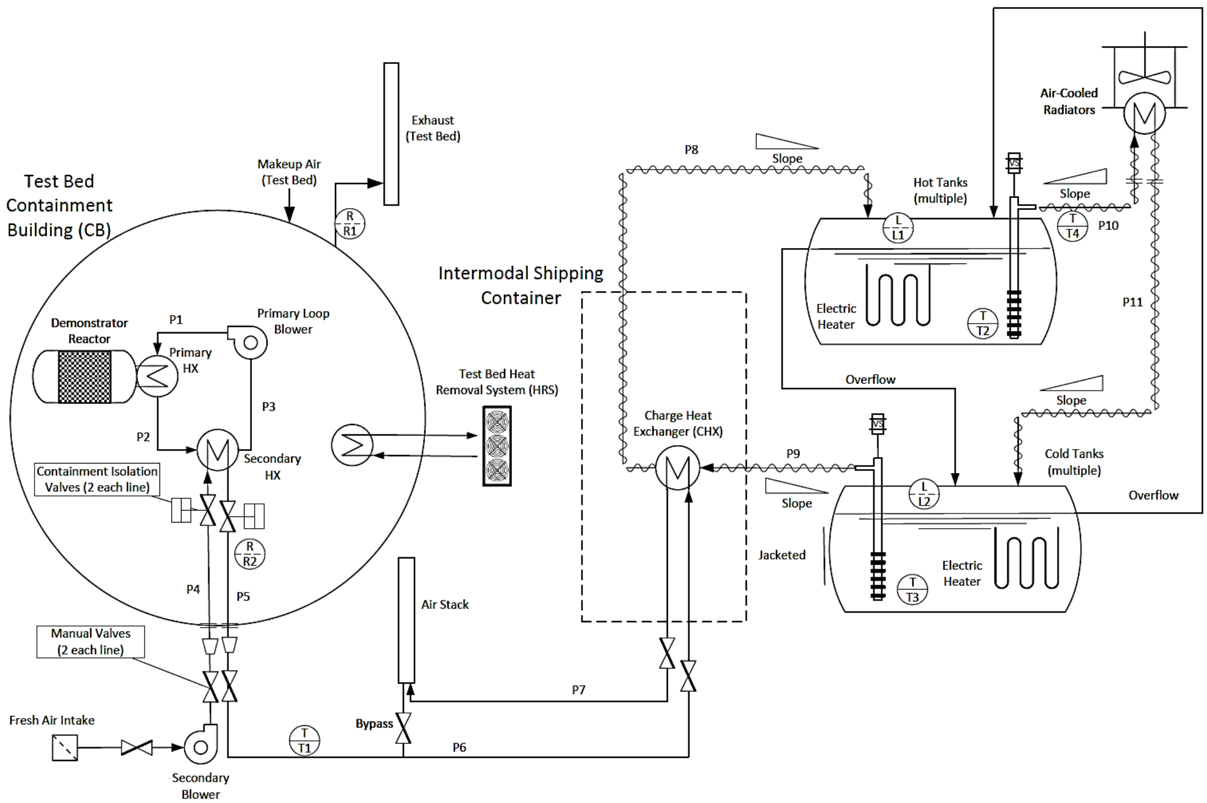


Figure 4. 2-D concept of operation for the AR-IES island.

4 Design and Operating Conditions

The AR-IES will feature the design and operating conditions listed in Table 1. The design temperatures and flow rates were selected to accommodate the expected heat loads and temperature of a universal high-temperature gas-cooled microreactor at DOME. Because HITEC molten salt ($NaNO_3$-KNO_3-$NaNO_2$, 7-49-44 wt%) has a relatively low melting point (142°C) and a high operating temperature range (stable at up to 550°C), the system is capable of storing high-temperature heat at around 420°C. Table 2 shows the thermophysical properties of the molten salt when at the nominal temperatures. The maximum design temperature and pressure was established as 750°C and 7 MPa on the heat delivery side (hot air, reactor heat) of the charge heat exchanger, which was sized to 2 MW_{th}. The nominal flowrate was based on a heat transfer analysis of the flowrate required to heat the molten salt from 420°C to 267°C, using 2 MW of heat input from the charge heat exchanger. The discharge (heat rejection side) was similarly sized so as to reject up to 2 MW_{th} from the storage system.

Table 1. Nominal design and operation conditions for the AR-IES.

Condition	Nominal Value
Hot molten salt temperature	420°C
Hot molten salt pressure	120–400 kPa
Cold molten salt temperature	267°C
Cold molten salt pressure	120–400 kPa
Compressed hot air or gas maximum temperature	750°C
Compressed hot air or gas maximum pressure	7000 kPa

Table 1. (continued).

Condition	Nominal Value
Nominal charge heat exchanger duty	2 MWth
Nominal discharge load duty	2 MWth
Nominal molten salt mass flow at nominal duty	10.7 kg/s
Nominal storage duration	4 hours
Nominal storage capacity	4 MWhth
Molten salt mass	225,500 kg
Molten salt volume	125 m3
Tank built-in heaters heat tracing temperature	420–450°C

Table 2. HITEC thermophysical properties at nominal temperatures.

Temperature	Density (kg/m3)	Thermal Cond. (W/m-K)	Viscosity (cP)	Heat Capacity (kJ/g-K)
267°C	1884	0.5717	4.595	1.293
370°C	1809	0.6379	2.055	1.190
420°C	1772	0.6822	1.581	1.135

5 Project Status and Summary

The operating conditions and design requirements have been identified and documented in a functional and operational document (i.e., FOR-856) that has already been reviewed in the electronic change request (eCR) system (see Appendix A). Comments obtained via this review were incorporated into the final version and entered into the INL Electronic Document Management System (EDMS). When the project proceeds to the next step, FOR-856 will be submitted to engineering services for use in designing the piping, necessary support structures, and utilities needed to operate the AR-IES. A design review, involving both internal and external stakeholders, will be conducted for the AR-IES design, though additional meetings must be held prior to finalizing the design and moving forward with procurement following the formal program approvals. A Concept of Operations (Con-Ops PLN-6732) has also been drafted and reviewed (see Appendix B). A funding determination for the project (WES-EST-23-488) was completed by Walsh Engineering Services. Two formal quotations from two different vendors were received, and there were found to align with INL’s internal funding determination estimates.

Appendix A

Functional & Operational Requirements

Document ID: FOR-856
Revision ID: B
Effective Date: DRAFT

Functional and Operational Requirements

Advanced Reactor Integrated Energy System (AR-IES) Platform

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance.

CONTENTS

1. INTRODUCTION

Integrated energy systems (IES) that pair industrial thermal energy loads with advanced reactors (ARs) are the main topic of this research. The Idaho National Laboratory (INL) Crosscutting Technology Development Integrated Energy System program and the National Reactor Innovation Center (NRIC) are seeking to develop, design, and construct an AR-IES demonstration platform (hereafter referred to as "the Platform") that couples an AR's thermal output to a variable capacity load emulator (i.e., air-cooled radiator) and sensible thermal energy storage (TES). A two-tank molten-salt TES system was selected as the representative storage technology for demonstrating the use of TES within an integrated system, but this selection should not be interpreted as the primary storage option for all AR-IES.

ARs are currently being designed for operation at the Materials and Fuels Complex (MFC). MFC-767 is an ideal location for ARs, as it formerly housed a similar-sized reactor. A project called the Demonstration and Operation of Microreactor Experiments (DOME) will modify MFC-767, MFC-768, and the surrounding area to create a test bed to support the demonstration and operation of these ARs.

The AR-IES will demonstrate the transfer of reactor thermal energy generated at a constant rate and temperature, as well as the storing of energy for users who require the provision of thermal energy at variable rates and/or different temperatures.

1.1 Description of the Envisioned AR-IES System

- Allocated Space: It was proposed that the platform be located within 10–200 ft of the DOME site (exact location to be determined), on a transportable skid.
- Charge-Side Heat Exchanger: To be comprised of a single heat exchanger (gas-to-molten-salt heat exchange), with gas from DOME (as the reactor is being tested in DOME) being circulated through the IES charge heat exchanger.
- TES System: Two sets of TES tanks, one set to store cold salt and the other to store hot salt. Each of the two cold and hot tank sets will include one to four tanks.
- Piping and Pumps: For drawing molten salt from the TES tanks, then pushing it through the platform heat exchangers and back around to the TES tanks.
- Discharge-Side Controllable Load: The discharge side of the TES tanks is connected to a variable/controllable heat load emulator that rejects heat to the atmosphere via an air-cooled radiator or chiller plant.

1.2 Description of Engineering Task

This document identifies the functional requirements and the performance required of the Platform.

1.3 Description of the End-Use for the Engineered Item or Activity

The Platform will enable demonstration of a fully functional and diverse TES system for model validation, as well as an initial technology demonstration of fully coupled microreactors with industrial loads. In this manner, commercial risk for reactor developers can be reduced prior to full-scale demonstrations, and nuclear reactor systems can be tested at-scale in a controlled environment so as to accelerate the deployment of systems featuring flexible industrial heat delivery capabilities and integrated TES.

The Platform will also support the development of flexible electrical generation and enable the deployment of nuclear power plants featuring industrial heat delivery capabilities, through the designing if a fully functional and diverse set of heat loads for validation and initial technology demonstration purposes.

2. OVERVIEW

2.1 Ownership of the FOR

The assigned MFC engineering manager is the owner of this FOR. Once assigned, ownership will be transferred to the Cognizant System Engineer.

2.2 End-User of Engineered Item or Activity

The Nuclear Facility Manager is the end user of the as-modified facility.

3. ENGINEERING INPUTS

Curly brackets "{}" indicate preliminary information. Square brackets "[]" refer to a database ID or a source document.

The requirements found in Sections 3.1, Functional Requirements, and 3.2, Performance Requirements, can be presented in terms of a hierarchy:

1. **Platform Requirements**: The first indentation lists requirements that apply to two or more systems. These requirements are decomposed into system requirements.

2. **System Requirements**: The second indentation lists requirements that apply to two or more components. These requirements are decomposed into component requirements.

3. **Component Requirements**: The third indentation lists requirements that apply to a specific component. These requirements are incorporated within construction and procurement specifications.

3.1 Functional Requirements

3.1.1 Direct Hot Gas

The gas loop (GL) shall direct hot gas from the outlet of the test-bed gas heat exchanger (TBGHX) interface in the following two ways: through the charge heat exchanger (CHX) and back to the inlet of the external test-bed gas compressor, and/or to an air mixing system. As needed, the GL shall direct the test-bed gas compressor intake from the atmosphere.

3.1.1.1 Connect to the TBGHX

The GL shall connect to the TBGHX thermal sleeve at the flange just outside the DOME.

3.1.1.1.1 Reduce Piping Size

The GL shall reduce the size of the piping to match the gas inlet of the CHX.

3.1.1.1.2 Isolate Gas Systems

The GL shall isolate the TBGHX from the CHX and the CHX from the TBGHX.

3.1.1.2 Connect to the CHX

The GL shall connect to the CHX to convey heat from the reactor.

3.1.1.3 Divert Excess Heat

As needed, the GL shall divert heat from the reactor to the air mixing system for release to the atmosphere, bypassing the CHX.

3.1.2 Transfer Reactor Heat

The CHX shall draw thermal energy from the GL and transfer it to the to the molten-salt circulation system (MSCS)

3.1.3 Circulate Molten Salt

The MSCS shall draw from the TES tanks, route the salt through the CHX, and then route it back to the TES tanks.

3.1.3.1 Connect MSCS Components

The MSCS shall connect to the various MSCS components.

3.1.3.1.1 Connect to the CHX

The MSCS shall connect to the nozzles on the shell side of the CHX.

3.1.3.1.2 Connect to TES System Tanks

The MSCS shall connect to the inlet of the TES system tanks.

3.1.3.1.3 Connect to Molten-Salt Pumps

The MSCS shall connect to the outlet of the MSCS pumps.

3.1.3.1.4 Connect to the DHX

The MSCS shall connect to the nozzles on the shell side of the Discharge Heat Exchanger (DHX).

3.1.3.1.5 Maintain Molten State

The MSCS piping shall maintain the molten state of the salt.

3.1.3.1.6 Drain Molten Salt

The MSCS piping shall drain molten salt from the piping and the CHX when circulation is halted.

3.1.3.1.7 Direct Overflow

The MSCS shall direct overflow from one TES tank group to the other.

3.1.3.2 Pump Molten Salt

The molten-salt pumps shall draw molten salt from the TES system tanks, then push it through the heat exchangers and back to the TES system tanks.

3.1.3.2.1 Melt Salt

The electric immersion heaters shall melt salt in the TES system into a liquid form for pumping.

3.1.3.2.2 Moderate Flow

The molten-salt circulation pumps shall moderate the flow of recirculating molten salt.

3.1.4 Store Reactor Heat

The TES system shall store reactor heat in the form of molten salt.

3.1.4.1 Contain Molten Salt

The TES system tanks shall contain molten salt as the heat storage medium.

3.1.4.2 Limit Heat Loss

The TES system shall be configured to limit the heat lost from the system.

3.1.5 Draw Stored Heat

The Platform shall emulate thermal energy users who draw thermal energy from the TES system at a variable rate.

3.1.5.1 Transfer Stored Heat

An air-cooled radiator shall draw heat from the MSCS.

3.1.6 Sense Conditions and Respond to Control Signals

The Platform shall provide the additional instrumentation needed to validate models of the integrated systems.

3.1.7 Draw and Distribute Power

The Platform shall draw and distribute power to support electrical equipment.

3.2 Performance Requirements

3.2.1 Direct Hot Gas

The GL shall be designed to operate at a pressure range up to 7,000 kPa.

The GL shall be designed to operate within a temperature range of 200–750°C.

The GL shall be designed to circulate {xx kg/s} of hot air. *"highlighted: to be determined"*

3.2.1.1 Connect to the TBGHX

The properties of the GL flange at the TBGHX interface shall match the properties of the TBGHX flange. The TBGHX flange is {16} in. in diameter.

3.2.1.1.1 Reduce Piping Size

The GL shall reduce the size of its piping from the {16-in.} TBGHX flange down to 6.875 in.

3.2.1.1.2 Isolate Gas Systems

The GL shall provide a manual isolation valve at the inlet and the outlet side of the CHX.

The GL shall provide a manual isolation valve at the inlet and the outlet side of the TBGHX interface.

3.2.1.2 Connect to the CHX

The GL shall connect to the 6.875-in. nozzles on the tube side of the CHX.

3.2.2 Transfer Reactor Heat

The CHX shall be sized to transfer up to 2 MW of thermal energy.

3.2.3 Circulate Molten Salt

The MSCS shall be designed to achieve a mass flow rate of 10.75 kg/s.

The circulation system shall be designed for molten salt whose viscosity is {P01} cP. *"highlighted: to be determined"*

The design pressure of the MSCS is {P02} kPA. *"highlighted: to be determined"*

3.2.3.1 Connect MSCS Components

The MSCS shall provide piping between the CHX, the TES system tanks, the MSCS pumps, and the DHX.

3.2.3.1.1 Connect to the CHX

The MSCS connection with the CHX shall take the form of a 7.625-in.-ID flange.

3.2.3.1.2 Connect to TES System Tanks

The MSCS shall connect to the {P03}-in. inlet nozzle of the TES system tanks

3.2.3.1.3 Connect to Molten-Salt Pumps

The MSCS shall connect to the {P04}-in. outlet of the MSCS pumps.

3.2.3.1.4 Connect to the DHX

The MSCS connection to the DHX shall take the form of a 4-in. flange.

3.2.3.1.5 Maintain Molten State

The MSCS piping shall be insulated and heat-traced to prevent a temperature drop of {10°F} from the TES system tanks to the CHX. *"highlighted: to be determined"*

3.2.3.1.6 Drain Molten Salt

The molten salt circulation piping shall be sloped at {0.25} in. per foot. *"highlighted: to be determined"*

The CHX shall be elevated relative to the TES system tanks.

3.2.3.1.7 Direct Overflow

The TES system tanks shall be connected at the headspace above the operating volume of each tank.

3.2.3.2 Pump Molten Salt

System pumps shall circulate molten salt at a variable mass flow rate of 0–10.75 kg/s.

3.2.3.2.1 Melt Salt

The electric immersion heaters shall be positioned near the projected salt surface at{xx feet}from the tank bottom. *"highlighted: to be determined"*

3.2.3.2.2 Moderate Flow

The control system shall be capable of varying the output from the molten-salt circulation pumps.

3.2.4 Store Reactor Heat

The Platform shall store the total heat output from the reactor produced over {P04} hours. *"highlighted: to be determined"*

3.2.4.1 Contain Molten Salt

The operational volume of the TES system tanks shall be {P05}. *"highlighted: to be determined"*

At the maximum pumping rate, the headspace within the tanks above the operational volume shall hold one minute of pumped salt.

3.2.4.2 Limit Heat Loss

The TES tanks shall be grouped together to share thermal energy.

The TES tanks shall be placed in an insulated enclosure that limits heat loss to {P06} kJ/hr. *"highlighted: to be determined"*

3.2.5 Draw Stored Heat

One thermal energy user shall be emulated, using an air-cooled radiator.

The Platform shall be capable of switching to emulate an alternate user.

3.2.5.1 Transfer Stored Heat

The heat drawn from the MSCS shall vary from 0 to 2 MW of thermal energy.

3.2.6 Sense Conditions and Respond to Control Signals

The Platform shall provide a dedicated I/O chassis that senses operating conditions, transmits the data to the test-bed instrumentation and control system (ICS) and responds to control signals from the ICS.

3.2.7 Draw and Distribute Power

The system shall draw its power from the SWGR-767 480 V bus.

3.3 Maintenance Requirements

Anticipated maintenance activities shall be limited to 1 hour.

Maintenance of the MSCS shall be performed only after it has been shut down and molten salt has been drained to the TES system tanks.

Maintenance of equipment adjacent to the DOME shall be limited while the reactor is operating.

The Platform shall be maintainable in adverse weather conditions typical of the selected location.

3.4 Owner-specified Technical Requirements

3.4.1 Integrability

The Platform shall be physically integrated within the DOME test bed.

The Platform shall be operationally integrated with the demonstration reactor within the DOME test bed.

The Platform shall be designed as a non-nuclear facility that is adjacent to, and interfaces with, nuclear facilities.

The Platform shall be designed and operated within the regulatory framework identified in INL Standards 139 and 142, as applicable.

3.4.2 Versatility

The Platform shall accommodate a variety of demonstration reactors, without the need to be reconfigured.

3.4.3 Adaptability

The Platform design shall include margin-to-envelope uncertainties.

3.4.4 Flexibility

The Platform design shall be responsive to input from demonstration reactors.

3.4.5 Scalability

The sizing of Platform equipment shall be scalable in response to specific parameters.

3.4.6 Modifiability

The Platform shall be modifiable to incorporate a variety of users that draw heat from the TES system.

3.4.7 Survivability

The Platform shall be designed for a molten salt minimum temperature of 420°C on the hot side.

The equipment within the Platform shall have a demonstrated history of surviving outdoor temperatures such as those experienced in the MFC.

The Platform shall be designed to resist corrosion from mixtures of sodium nitrite, sodium nitrate, and potassium nitrate.

The Platform shall be designed to survive anticipated thermal cycling.

3.4.8 Transportability

Platform equipment shall be designed to be transported via standard highway tractors and semi-trailers.

3.4.9 Constructability

Platform equipment shall be assembled and installed onsite, using standard construction equipment. Heavy items shall have lifting features for positioning within the allocated areas.

3.4.10 Operability

The Platform shall be monitored and operated remotely via the test-bed ICS.

3.4.11 Maintainability

The Platform equipment shall be accessible, and the design shall include a listing of spare parts and the special tools needed for calibration and maintenance.

3.5 Supporting Information

3.5.1 Need for Configuration Management

Modifications to MFC facilities and the DOME design will be configuration managed in accordance with MFC engineering processes.

3.5.2 Sensitive Information

The intellectual property of project stakeholders shall be access controlled and limited to those possessing a need to know.

3.5.3 Export Control

INL export control processes shall be followed when providing information to outside entities.

3.5.4 Need for Engineering Change Control

Engineering change control will follow SP-30.1.2, MFC and TREAT Facility Modification Control.

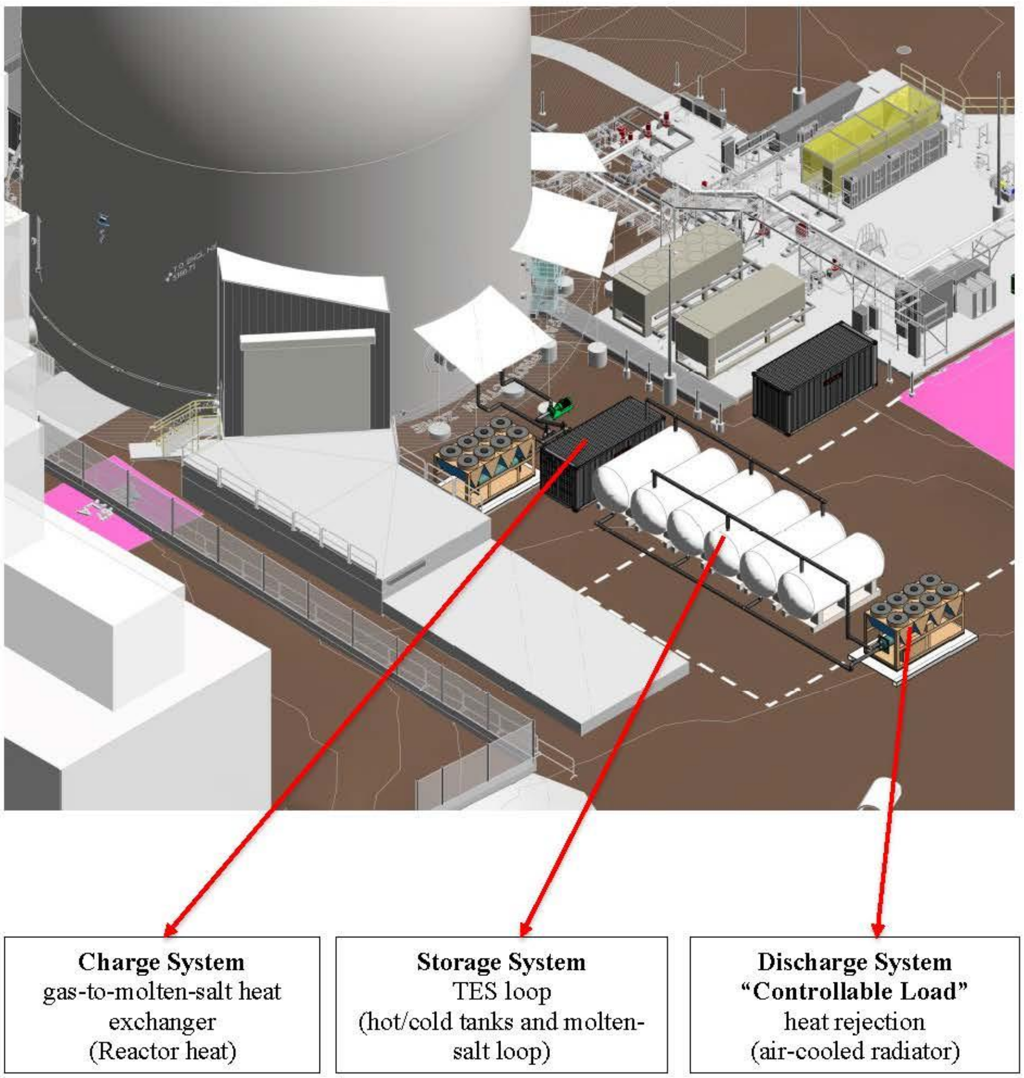
3.5.5 Level of Verification Needed

The minimum level of verification for all elements will be a technical check and informal design review. Additional rigor will be applied when deemed necessary by the Technical Integrator and based on the quality level of Platform components.

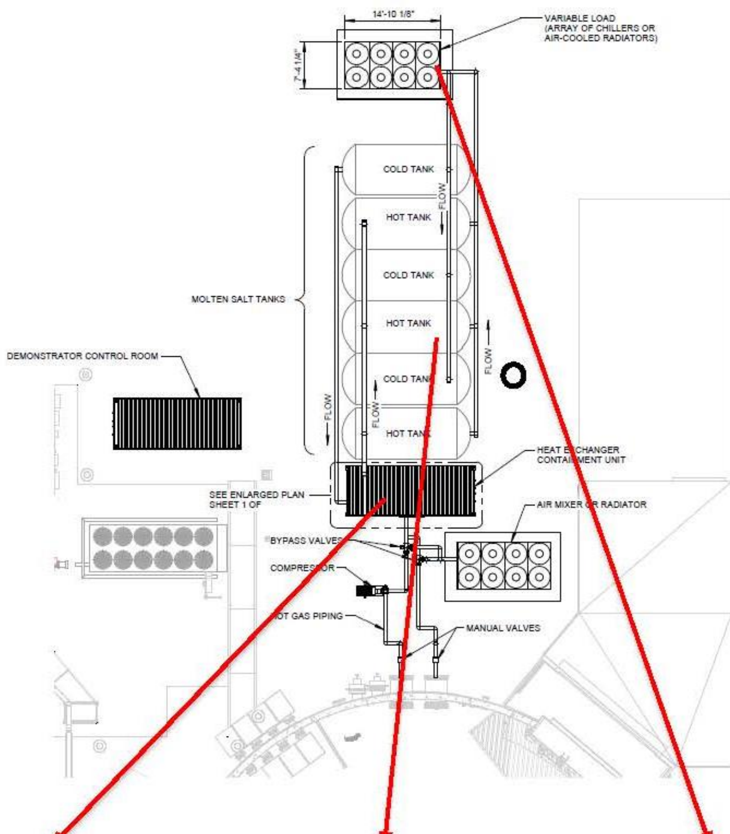
3.5.6 Technical Integrator

The MFC Reactor Project Engineering Manager (or his delegate) is the Technical Integrator for this work.

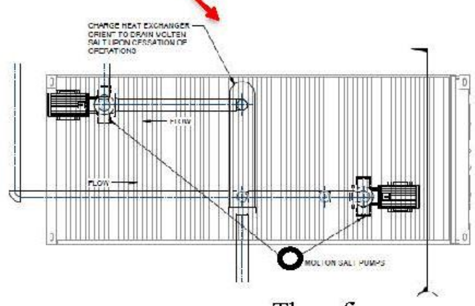
Preliminary Drawings



These figures are conceptual in nature only.



Charge System gas-to-molten-salt heat exchanger (reactor heat)	**Storage System** TES Loop (hot/cold tanks and molten-salt loop)	**Discharge System** heat rejection side (air-cooled radiator or chiller)



These figures are conceptual in nature only.

Appendix B

Concept of Operations

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Effective Date: DRAFT

Concept of Operations

Advanced Reactor Integrated Energy System (AR-IES) Project

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Table of Contents

1 INTRODUCTION

This Concept of Operations (ConOps) document identifies user needs and system functions at the top level of the technical baseline for the Advanced Reactor Integrated Energy System (AR-IES) Demonstration Platform (the Platform). As such, this document is the precursor to the Functional and Operational Requirements (F&OR) document described in LWP-10000 *Engineering Initiation*. The F&OR is the highest level of documentation and control of engineering inputs.

As an element of the technical baseline, the ConOps is a living document that will be modified throughout the lifecycle of the program consistent with project evolution. The objective is to align all the activities within the AR-IES Project.

1.1 Project Description

The AR-IES Project refers to the development and delivery of the Platform to meet the needs of the AR-IES stakeholders.

The AR-IES is a new demonstration platform designed to take the thermal output from demonstration reactor, demonstrate thermal storage, and emulate thermal load that varies hourly and by season. This concept is consistent with molten salt systems currently planned for the commercial nuclear industry.

Modifications of existing and planned facilities are required. This includes modification of the INL/NRIC Demonstration of Microreactor Reactors (DOME) Test Bed using the Experimental Breeder II (EBRII) dome Containment Building (CB) and the Materials and Fuel Complex (MFC) infrastructure. The modifications include the reconfiguration an existing equipment planned within and outside of the CB. Most significant are the interfaces with the demonstration reactors, penetrations of the CB, and penetrations of the radiation shielding surrounding the demonstration reactor. Additionally, the Platform will need support systems such as electrical, HVAC, instruments, and controls (I&C).

1.1.1 Background

The Idaho National Laboratory (INL) is a unique asset within the DOE complex as a facility with a long history of developing and demonstrating low-power reactors of various types. The facilities within the INL reactor sites operate within mature nuclear safety bases and qualified nuclear operations staff. One such facility under development is the INL/NRIC Demonstration of Microreactor Reactors (DOME) test bed using the Experimental Breeder II (EBRII) dome within the Materials and Fuel Complex (MFC)

These attributes, together with available space and ongoing design development, make the DOME Project well suited to coordinate design, construction, and operation with the AR-IES Project consistent with established nuclear safety processes and protocols.

1.1.2 Assumptions and Constraints

The following are fundamental assumptions for AR-IES:

1 Design and construction of the AR-IES is coordinated with the design and construction of the DOME test bed. The construction of the DOME test bed and the AR-IES platform occurs concurrently to achieve economy of scale.

2 The physical interfaces of the AR-IES allow for a wide variety of reactor demonstrations to be installed, connected, operated, maintained, dismantled, decommissioned, and disposed, with an initial focus on the use cases outlined in Section 6.

3 The dismantling and decommissioning activities leaves the test bed and the AR-IES in a condition that enables their reuse for further demonstrations.

4 The operating capabilities of the AR-IES bound the operating parameters of the demonstration reactors.

5 The AR-IES does not require complex safety components that complicate design, construction, and operation of the reactor and the Test Bed.

1.2 Overview of the Envisioned System

This section provides an executive summary overview of the envisioned system. A more detailed description will be provided in Section 3.0

1.2.1 Overview

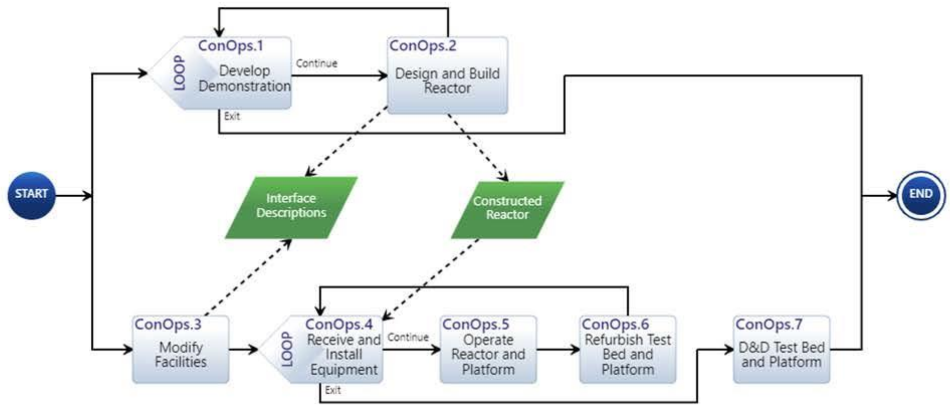

Figure 1. Overview

Figure 1 presents an overview of the AR-IES concept of operation:

1 **Reactor Development**: Several projects, separate from the AR-IES project, develop the designs and procedures necessary to install, operate, decommission the Reactor and its test bed. An Interface Description Document (IDD) coordinates the AR-IES with the test bed, MFC infrastructure, and INL procedures.

2 **Platform Assembly and Transport**: The project that develops the Platform also procures construction materials and equipment. The equipment is designed and packaged for transport to the designated INL interim storage location for subsequent receipt and inspection.

3 **Facility Modification**: The AR-IES project develops the designs and procedures necessary to install, operate, and decommission the Platform in accordance with PDD 10000 Conduct of Engineering. Contracted construction forces procure, assemble, and test materials and equipment for the platform in accordance with drawings and specifications. The Platform is commissioned and turned over to operations in accordance with Management Control Procedure MCP-7460, Project Turnover, Acceptance, and Closeout.

4 **Receipt and Installation**: The INL procurement organization receives, inspects, and stores equipment in accordance with TPR-13428, Construction

Receipt Inspection. Construction forces position, connect, and commission the Platform in accordance with drawings and specifications. INL Procurement incorporates construction records in EDMS and Asset Suite for the Platform.

5 **Reactor Operation**: INL Operations operates the test bed, the Reactor, and the Platform in accordance with the procedures that were developed as a collaborative effort by the each of the participating projects.

6 **Equipment Refurbishment**: Construction forces prepare the Test Bed and the Platform for the next Reactor. INL Engineering updates records in EDMS and Asset Suite.

7 **Test Bed and Platform Decommissioning**: Construction forces decommission and remove Test Bed and Platform equipment in accordance with procedures. INL Engineering updates records in EDMS and Asset Suite.

1.2.2 Platform Scope

The Platform scope is as follows:

- **Allocated Space**: The space available for the Platform is just West of the DOME Project as shown in Figure 2.

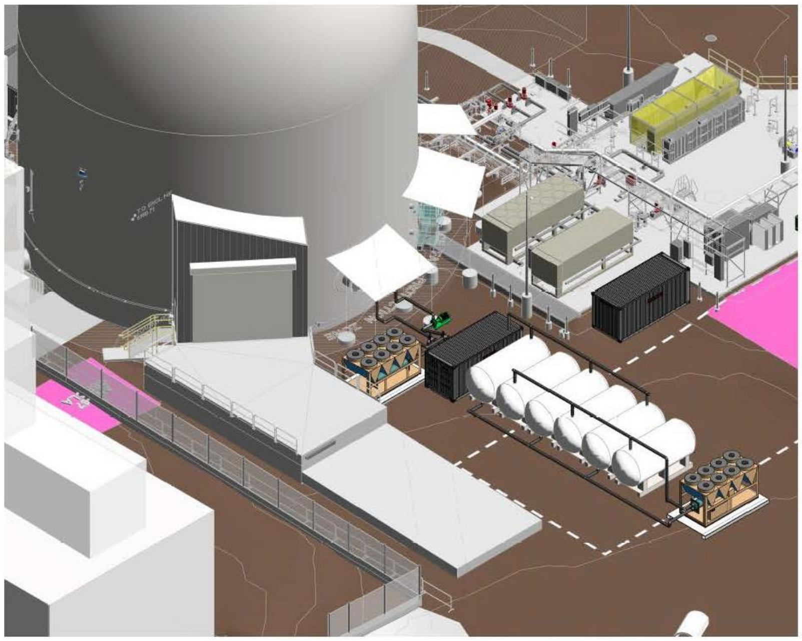

Figure 2. Available Space Within the DOME YARD Area

- **Allocated Penetrations**: As shown in Figure 3, the transfer of heat from within the CB to the Platform is through 40 in sleeves that surround a 24 in pipe that will probably be reduced to 16 in. The sleeves prevent damage to the structure of the CB. The Platform connects to a 16 in flange just outside of the CB.

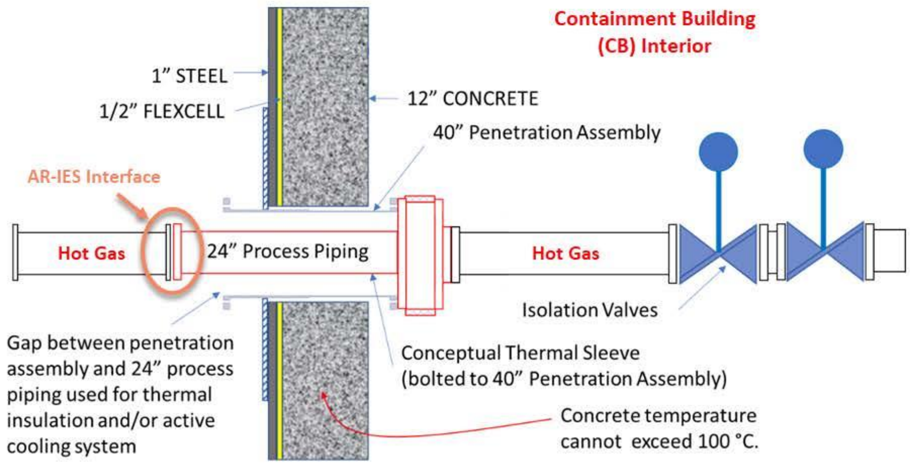

Figure 3. Allocated Penetrations of the CB

- **Thermal Energy Storage (TES) Tanks**: The Platform includes two sets of Thermal Energy Storage (TES) Tanks. One set stores cold salt relative and the other set that stores hot salt. Each tank has openings for the introduction of salt, an electric immersion heater, instrumentation, and check valve to relieve internal pressure.
- **Heat Exchangers**: The Platform includes two heat exchangers:
  - A gas-to-molten salt heat exchanger to charge TES tanks with heat
  - A molten salt-to-liquid heat exchanger to discharge heat from TES tanks
- **Piping and Pumps**: The platform includes pumps that draw molten salt from TES tanks, push the salt through the Platform heat exchangers, and back to the TES tanks.

2 DOCUMENTS

This section describes the artifacts comprising the technical baseline and reference documents that provide supplemental information and guidance.

2.1 Applicable Artifacts

The term "artifacts" refers to analyses, definitions, requirements, databases, models, classification schemes, reports, and technical papers. The following are the major artifacts that underpin the Project:

- **Functional Analysis**: Identifies the functions to be satisfied by the Platform. It provides input to various artifacts such as the F&OR and Value Engineering (VE).
- **Value Engineering (VE)**: A study defined in GDE-70-K, Value Engineering. The VE process evaluates the Project and the Platform to determine the best value in terms of functionality per unit cost. Use of a VE process is required by the Department of Energy and is otherwise a good business practice.
- **Requirements**: As defined in LWP-10105, Facility / System Requirements Documentation (COR / T&FR / SDD), the technical baseline is the documentation that defines the design, operation, and maintenance requirements or depicts the physical configuration of a system, structure, or component (SSC). This baseline includes document types such as technical and functional requirement (T&FR), system design description (SDD), documented safety analysis (DSA), technical safety requirement (TSR), specifications, engineering calculation and analysis report (ECAR), technical evaluation (TEV), Vendor Data, operation, and maintenance manual (O&MM), preventive maintenance in the form of a justification or drawing.
- **Requirements Management (RM) Application**: Manages the requirements for the Project. The RM application identifies the current technical baseline and manages proposed changes to that baseline. It is relational to trace each requirement to its basis and to its verification process. The database for the Project is maintained in the "cloud" to provide accessibility to a wide range of Project stakeholders to enhance collaboration.
- **Digital Models**: Digital models underpin the design of the Platform before the design is released for construction. They provide an inexpensive verification of the design relative to the expense of construction, thereby reducing risk to the Project.
- **Classification Schemes**: Structures the digital models and the organization of the Project. The output from this analysis will be incorporated in an OmniClass classification scheme which provides the ultimate traceability of the design, the physical platform, and procedures to the design and safety basis. This realizes configuration management (CM) for the Project and the Platform.
- **Reports**: Identify the readiness of the project for design, construction, and operation.
- **Technical Papers**: Describe the design of the Platform and the results of the investigation. These papers are of general value to nuclear entities considering the integration of thermal storage in their projects.

2.2 Reference Documents

Code of Record (COR): The COR for the Platform is identified in INL Standards STD-139 and STD-142.

3 DESCRIPTION OF ENVISIONED SYSTEM

This section provides a more detailed description of the envisioned system and its operation as contained in the following subsections.

3.1 Needs, Goals and Objectives of the Envisioned System

3.1.1 Needs

A system like AR-IES is required to acquire the data needed to establish credibility in the heat transfer concepts, safety requirements, and operation of thermal storage systems integrated with nuclear reactors.

3.1.2 Goals

The goal is to establish a small-scale demonstration platform that will be applicable to, and useful for, just about any reactor concept needing testing and demonstration of heat transfer physics and fluid dynamics. The experience gained with the integration of small modular reactors and with AR-IES can be leveraged for the transition of larger scale demonstrations in the coming years, reducing the overall timeline for new reactor concept development and deployment.

Specifically, the development and operation of the Platform provides the following types of publications for consumption by commercial industry:

- **Process Data**: Model validation - comparing actual measurements vs that predicted by models.
- **Rationale**: Explain why molten salt vs sand; nitrate vs chloride salts; Platform configuration
- **Design Basis Model**: The International Council on Systems Engineering (INCOSE) calls for papers related to system development.
- **Standard Specifications**: Entities such as INL publish a standard set of construction specifications that have already been reviewed and approved for use. Having a standard library accelerates engineering, procurement, and construction processes. Specification libraries such as those available from the Las Alamos National Laboratory (LANL) have very few that are applicable to process equipment. The design of this Platform will result in the development and use of specifications in the following MasterFormat divisions:

  - Division 40 - Process Interconnections
  - Division 41 - Material Processing and Handling Equipment
  - Division 42 - Process Heating, Cooling, and Drying Equipment
  - Division 43 - Process Gas and Liquid Handling, Purification, and Storage Equipment

3.1.3 Objectives

The objectives of the project are:

- Demonstrate a way to integrate a thermal energy storage (TES) system with:
    - Nuclear reactors that provide a source of thermal energy
    - Thermal energy users who don't draw thermal energy at a constant rate
    - The infrastructure needed to operate the integrated systems
- Use existing analyses, building, and facility support systems to reduce financial and safety-related risks. The CB building is already qualified as a reactor site with experienced operators and has the infrastructure and the expertise needed to identify interfacing equipment such as shielding, I&C cabinets, control panels, power generation systems, heat rejection units, etc.

3.2 Overview of Key System Elements

3.2.1 System Elements

Figure 4 illustrates the functionality of specific Platform elements

1 **Charge Side**: Air-to-Molten Salt Heat Exchanger: The reactor heats air that is circulated through a Charging Heat Exchanger (CHX). The air is compressed to enhance its heat transfer properties.

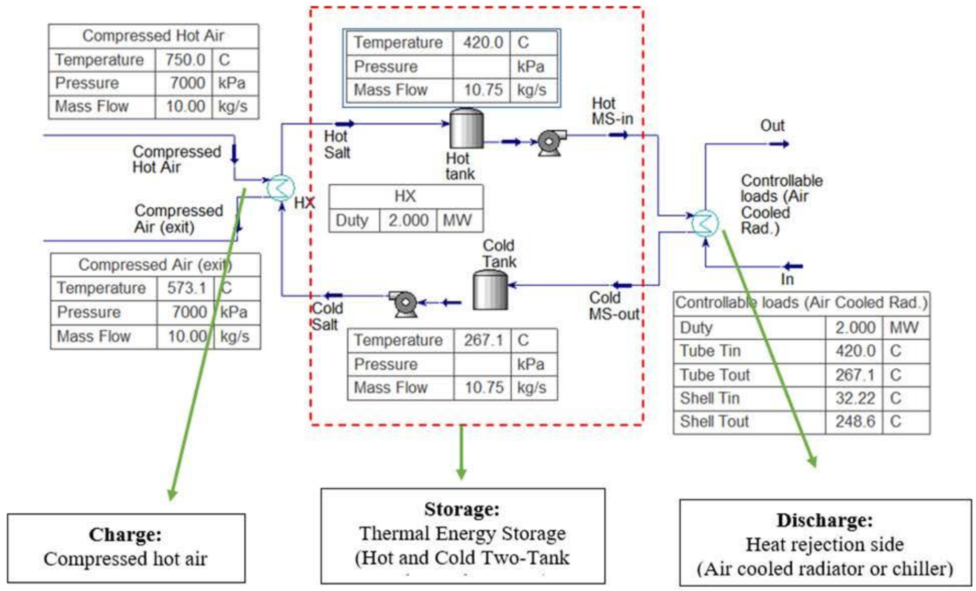

Figure 4. Functionality of System Components

2 **Cold Salt Pump**: The Cold Salt Pump draws molten salt from the Cold Salt Tank and pushes it through the CHX to the Hot Salt Tank.

3 **Hot Salt Pump**: The Hot Salt Pump draws molten salt from the Hot Salt Tank and pushes it through varied loads (for example, an Air-Cooled Radiator) to the Hot Salt Tank.

4 **Hot Salt Tank**: The Hot Salt Tank provides thermal storage of the reactor heat. Reactors run continuously at steady state even when their power is not needed. The Hot Salt Tank stores the excess energy from the reactor so that the reactor is used more efficiently. Excess energy is drawn from thermal storage when the demand exceeds the output from the reactor.

5 **Discharge Side**: Heat is drawn from the Hot Salt Tank and rejected using a Heat Exchanger/Radiator: The discharge side of the Hot Salt Tank emulates heat transfer to a heat exchanger that is connected to a thermal load such as a steam turbine. In this demonstration, the thermal energy is simply rejected to the atmosphere using an air-cooled radiator or chiller plant.

6 **Backup Electrical Lines**: Backup electrical lines provide long term backup power to critical loads. The critical uses of this power are heat to the molten salt loop when the reactor is not running, instrumentation and controls (I&C),

the control room, and communication networks to relay the information between the I&C equipment and the control room. These I&C systems may also need to be supplemented with uninterrupted power supplies to transition from normal power to backup generators.

7 **Standby Power**: The networks at CB are tied to Normal Power. In the event of a loss of power the network capabilities are lost. Adding the networks to standby power would improve the reliability of reactor monitoring for CB and other microreactors.

8 **Software**: Software is required to link the I&C with the user. Given the continually evolving nature of the system, the software will focus on creating an integrated development environment to facilitate the modification of code to meet the needs of the users. This means that the development platform must be scalable to add or remove hardware with ease, with the ability to perform real-time measurement and indication, and with generic analog/digital inputs and outputs using standard communication protocols. To this end, the software will be open-source (the source code is provided to the selected vendors) and will have examples or a baseline for the Platform software development. The development and operating software will also include tools that can be used to train operators on the look and feel of controlling the Platform. The software will include modules for measuring temperature, pressure, and control of the heat exchanger loops.

9 **I&C Systems**: The I&C system controls all the peripherals and links to the main human interface for command and indication. The DOME I&C hardware shared with the AR-IES Platform will include:

- Monitors in the control room
- A limited set of 'hard wired' controls in the control room
- Independent communication switches for fiber optics
- Fiber optic cables for analog signal transfer over long distances
- Control cabinets and auxiliary equipment for radiation detection.

10 **I&C Cabinets**: The I&C cabinets are linked in software and constitute the development platform with the ability to connect with temperature, pressure and other analog/digital inputs and outputs.

11 **Seismic Trip**: Microreactors installed in the test bed will require a dedicated seismic trip.

12 **Seismic Sensors**: Seismic sensors that have been qualified through the commercial grade dedication process will also be needed.

3.2.2 Potential Users

Multiple potential demonstrators have come forward from INL collaborators and other inquirers:

- **eVinci™ Micro Reactor**: Westinghouse is currently developing the eVinci™ Micro Reactor, a next-generation, very small modular reactor for decentralized remote applications. Westinghouse identifies integration with energy storage systems as one possible application.
- **Microreactor Application Research Validation and Evaluation Project (MARVEL)**: Because MARVEL is being designed for a two-year operational lifespan, it is not planned as an enduring asset. Upon MARVEL completion and decommissioning, the AR-IES Platform will be made available for subsequent users, whose testing durations would be similarly short by nature.
- **DOE and NASA**: DOE and NASA are collaborating on a lunar space reactor project (Fission Surface Power) that is expected to include earth-based demonstration and testing.
- **Department of Defense (DoD)**: The DoD has been investigating nuclear reactors as a strategic solution for energy needs, and a microreactor project supporting laser-based defense systems is anticipated to begin next year. AR-IES could also be used to test microreactor concepts developed by commercial companies.
- **General Atomics Company**: The General Atomics Company has expressed a strong interest in securing the use of AR-IES for testing of their reactor power system for the NASA/INL Fission Surface Power program. Quoting from their letter of support, The INL "facilities and support systems are ideal because the buildings are already qualified as a reactor site, and may already have existing interfaces with needed equipment such as shielding, I&C cabinets, control panels, power generation systems, heat rejection units, etc.
- **Molten Chloride Reactor Experiment (MCRE)**: MCRE is a liquid fueled, fast spectrum, Experimental reactor that will operate in the National Reactor Innovation Center (NRIC)-Laboratory for Operation and Testing in the U.S. (LOTUS) testbed. The principals of MCRE state that, "MCRE is designed to be the first of its kind fast spectrum irradiation of molten chloride fuel salt. As this is the first of its kind irradiation, the resulting approximately 300 liters of irradiated chloride fuel salt could be a significant resource for follow on salt characterization and radiolysis studies to further advance [technology readiness level] and understanding of the impacts of irradiated molten chloride salts.

Although some of these projects/programs may already be conducting research at INL, the AR-IES capability is generically applicable for all envisioned uses and is not being designed to support specific project needs. With the proposed modest investment of indirect funds, INL will make additional use of an existing facility in a relatively short amount of time for a variety of users.

3.2.3 MFC Organization

The MFC organization uses unique job titles that are well defined and used consistently throughout MFC procedures. To prevent possible confusion, these titles will be used in the procedures for AR-IES, the test bed, and the Reactor.

- **Facility Manager**: Directly responsible for the administrative and technical management of the Facility. He personally supervises or assigns competent supervision for all activities performed at the Facility.
- **Supervisor-in-Charge**: Certified to assume the responsibilities of the Manager, subject to restrictions imposed by the Division Director or the Manager, during the absence of the Manager, or acts for the Manager at other times in accordance with the authority delegated to him by the Manager.
- **Reactor Operation Supervisor**: Directs Reactor Operators and Electronics Technicians in the Operation and modification of the reactor and associated equipment. Is also certified to supervise steady state reactor operation and the shutdown of the reactor.
- **Reactor Operator**: Certified to operate reactor controls and load fuel and Reactors into the reactor.
- **Electronics Technician**: Certified to maintain the instruments and controls used on the reactor and associated equipment and performs the checkout procedures on this equipment required prior to reactor startup or transient operation. This is an operations position and should not be confused with that of the Electrical Maintenance Technician.
- **Maintenance Supervisor**: Qualified to direct MFC Maintenance Technicians in calibration and maintenance of equipment associated with the reactor or auxiliary systems.
- **Maintenance Technician**: Qualified for mechanical and/or electrical calibration and maintenance activities.
- **Others**: Several other positions are also identified in the MFC Operating Instructions.

3.3 Interfaces

In addition to the Reactor and the DOME Project, the AR-IES Project will interface with other organizations and facilities involved in performing the identified key Project functions.

3.3.1 Technical Project Lead (TPL)

A dedicated technical project lead (TPL) from INL will be assigned to each Reactor demonstration. The TPL will be the primary point of contact for the

Reactor staff throughout the course of the demonstration project, acting as its agent and steward at INL.

3.3.2 Key Interfacing Organizations

Key interfacing organizations include the following:

- **Microreactor Reactor Projects**: As described in this document.
- **Packaging and Transportation**: For questions and procedures related to the packaging and transport of hazardous, radioactive materials, and hazardous waste.
- **INL Transport Operations**: For the planning and execution of transport requirements.
- **National Reactor Innovation Center (NRIC)**: For programmatic planning and funding of microreactor Reactors.
- **External Entities**: Includes packaging vendors, external waste sites, etc. For example:

  - **Clive Disposal Facility**: For Class A waste.
  - **Waste Control Specialists (WCS)**: A comprehensive solution for the treatment, storage and disposal of Class A, B, and C low-level radioactive waste, hazardous waste and byproduct materials.
  - **PermaFix Northwest (PFNW)**: A commercial radioactive and mixed waste treatment and packaging facility.

- Materials and Fuels Complex (MFC)

  - **Nuclear Facility Operations**: Augmentation of AR-IES operations resources.
  - **Waste Generator Services**: Packaging and transfer of incidental CH-LLW (contaminated PPE, tools, etc.) to a storage location pending shipment for disposal.
  - **Nuclear Safety**: Development of the Safety Design Strategy (SDS) in accordance with DOE-STD-1189, Integration of Safety into the Design Process.
  - **Training**: Create and schedule instruction to ensure staff have the knowledge and skills necessary to safely and efficiently perform their work.
  - **Engineering**: Define technical requirements and review designs developed by contracted Architect/Engineering firms.
  - **Environmental**: Review and interpret regulations, laws, and directives, to identify environmental requirements applicable to the project.
  - **Maintenance**: Augmentation of AR-IES maintenance resources.

- **Characterization and Advanced Post-Irradiation Examination (PIE)**: Provides expertise, capabilities, data, and analysis of nuclear fuels and materials.
- **Project Management/Oversight**: Schedule projects and report status.
- **Quality Assurance**: Ensure compliance with NQA-1 and 2 program requirements and DOE Order 414.1D.
- **Radiological Controls**: Provide radiological controls to maintain and protect the radiological safety of MFC employees, the public and the environment.

3.3.3 Assets

Key INL assets interfacing with the AR-IES include the following:

- INL radioactive material handling facilities. For example:
  - **Idaho Nuclear Technology & Engineering Center (INTEC)**: For the safe transfer and storage of spent nuclear fuel in preparation for final disposal at an offsite repository or until the material is used for other purposes. The Center also has radioactive material storage and repackaging capabilities.
  - **Remote-Handled Low-Level Waste Disposal Facility (RHLLW)**: For permanent disposal of RHLLW.
- DOME equipment module handling system
- INL and offsite assets for performing identified functions (e.g., casks, transfer systems, facilities).

3.3.4 Initial Requirements

Initial sources of requirements include the following:

1 Disposal Waste Acceptance Criteria (WAC)

2 Safety Analysis Reports (SARs) of identified facilities

3 Requirements and Regulations

4 Idaho Department of Environmental Quality (IDEQ)

5 National Environmental Policy Act (NEPA)

6 DOE Orders

7 U.S. Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC)

8 INL rules and procedures

9 Baseline documentation as described above

10 Vendor interface requirements for commodities, construction, equipment, and services.

3.4 Modes of Operation

The major modes of operation for the Project are:

3.4.1 Design

Develop the designs and procedures necessary to install, operate, decommission the Platform. The design is coordinated with other projects using Interface Description Documents (IDDs). The primary outputs from this phase are calculations, construction drawings, and construction specifications.

3.4.2 Construction

Procure, assemble, and test materials and equipment for the Platform in accordance with drawings and specifications. Incorporate the output as records in EDMS and Asset Suite.

3.4.3 Equipment Integration

Receive, position, connect, and commission the Platform equipment in accordance with drawings and specifications.

3.4.4 Operation

Operate and maintain the Platform in accordance with procedures.

3.4.5 Reconfiguration

Prepare the Platform for the next Reactor and/or the next Heat Usage Demonstration. Update records in EDMS and Asset Suite.

3.4.6 Decommissioning

Decommission and remove Platform equipment in accordance with procedures. Update records in EDMS and Asset Suite.

3.5 Proposed Capabilities

In addition to the capabilities identified in Sections 3.2.1, the system provides the following capabilities:

3.5.1 Integrability

The Platform can be integrated with other systems, and within the spaces available for the arrangement of equipment and for performing work related to the operation of the Platform.

3.5.2 Versatility

The Platform can accommodate a variety of demonstration reactors without the need to change form.

3.5.3 Robustness

The Platform maintains its value in the context of changes from internal and external forces.

1 **Adaptability**: The Platform can respond to change from an internal change agent without losing its value.

2 **Flexibility**: The Platform can respond to change from an external change agent without losing its value.

3.5.4 Scalability

The size of Platform equipment can be scaled in response to changes in specific parameters.

3.5.5 Modifiability

The Platform can be modified, at an acceptable level of resource expenditure, to incorporate a variety of users that draw heat from the TES.

3.5.6 Survivability

The Platform can avoid or withstand hostile environments identified in Section 4.

3.5.7 Transportability

Platform equipment can be transported using standard highway tractors and semi-trailers.

3.5.8 Constructability

Platform equipment can be assembled and installed on site using standard construction equipment. Heavy items have lifting features for positioning within the allocated areas. Connections in radioactive environments that can be made with a remote operator.

3.5.9 Operability

The Platform can be monitored and operated remotely using the Test Bed Instrument and Control System (ICS).

3.5.10 Maintainability

The Platform provides accessibility to equipment, spare parts, and the special tools needed for calibration and maintenance.

4 PHYSICAL ENVIRONMENT

The Platform is required to perform under the following conditions:

- **Humidity and Elevation**: The MFC is in a high mountain desert in Idaho at an elevation of approximately 5200' above sea level.
- **Outside Temperatures**: Equipment external to the CB is subject to extreme heat and cold.
- **Other Natural Phenomena**: Other conditions that require consideration in the design and operation of the Platform include seismic, wind, and flood events.

5 SUPPORT ENVIRONMENT

Support for the system after it has been fielded will be as follows:

- **Maintenance Personnel**: Maintenance personnel are available at the AR-IES facility for the duration of its life. However, the Platform will have to develop a maintenance strategy that allows workers to meet the requirements of the INL Radiation Protection Program (RPP).
- **Critical Spare Parts**: Any critical spare parts that may be needed for the demonstration reactor should be provided by the reactor demonstrator. These spares will be placed in INL quality-controlled storage facilities until use or return to the rector demonstrator.
- **Engineering**: Engineering will continue to support the Facility and equipment modifications needed to support each new reactor.
- **Nuclear Safety**: Nuclear Safety will append the DOME FSAR for the Platform and for each new reactor.

6 OPERATIONAL SCENARIOS, USE CASES AND/OR DESIGN REFERENCE MISSIONS

This section identifies key use cases for the envisioned Platform. A use case is a function performed by an actor in an established role and further defined by a prompt, required inputs, and required outputs.

For this example, Company A is developing a novel advanced-reactor concept before proceeding with a commercial-scale prototype. It wants to verify the physics of the reactor core to be operated in the DOME Test Bed for 6 months. Company A elects to add to the benefits of the reactor demonstration by demonstrating thermal storage.

6.1 Development Activities

6.1.1 Review the Reactor Concept

The AR-IES Project conducts an initial review of the demonstration-reactor concept proposed by Company A against the capabilities of the AR-IES Platform as made available for the Reactor.

6.1.2 Execute Research and Development Agreement

After confirming that the Platform can be integrated with the demonstration reactor, Company A executes a cooperative research and development agreement with INL. The following scope is identified to be conducted by INL in collaboration with Company A:

- INL will conduct the technology development of the Platform as requested by Company A
- INL will work through the National Environmental Policy Act of 1969 (NEPA) and the DOE's authorization processes related to operation of the Platform.
- INL will receive shipment of the assembled Platform modules and take ownership at MFC
- INL will install the Platform and ready the integrated systems for commissioning
- INL will commission the integrated systems and prepare for critical operations using procedures developed in collaboration with Company A.
- INL will provide training, jointly with Company A, to INL nuclear reactor operators
- INL will operate the demonstration reactor, the Test Bed, and the Platform according to the plan developed in collaboration with Company A and the AR-IES Project

6.1.3 Develop Conceptual Reactor Design

When the contractual vehicle which enables this work is executed, Company A will already have a baseline conceptual-design package with detailed operating parameters and will be ready to share this information with appropriate INL staff. Platform design development begins concurrently.

6.1.4 Support Reactor Staff at INL

The TPL will work with Company A to identify engineering information and work products needed to support Company A's demonstration. On-site office space will be provided, as requested, for key staff from Company A during the project. The TPL will facilitate interactions between Company A's technical staff and the INL staff that will conduct work on various aspects of the Project.

6.1.5 Execute Regulatory Review

The integrated systems require a National Environmental Policy Act (NEPA) assessment and approval. The assessment must be re-evaluated for each specific reactor concept. Similarly, the existing DOE authorization and associated safety-basis documentation must be updated with analysis against Company A's specific design and configuration.

6.1.6 Finalize Reactor Design

Company A then works with INL to finalize the physical architecture and functionality of their demonstration reactor for use in the Test Bed and integration with the Platform. After a final design review is complete, Company A starts fabrication of their reactor.

6.1.7 Develop Plans and Procedures

Leveraging information from MFC procedures and previous demonstrations at INL, plans and procedures for installation, commissioning, operation, and deactivation of the Platform are developed.

6.1.8 Train Operators

INL operators are trained on all aspects of Company A's equipment and that of the Platform.

6.2 Integrated Startup

Refer to Figure 5 for integrated startup and operation.

1. Platform operators pour salt into the Cold and Hot Tanks. Measurements at L1 and L2 verify that the Tanks are at the level required for initial operation.
2. Test Bed systems are started and verified to be functional.
3. The Air-Cooled Radiator is activated and verified to be operational.
4. The salt within the Cold and Hot Tanks is melted using near-surface electrical immersion heaters.

5 Readouts at T2 and T3 verify that the salt is at a pumpable temperature.

6 The reactor is started and brought to full power.

7 A compressor pushes air or helium through the reactor core to acquire the heat generated by the reactor. That air is then pushed through the Test Bed Gas Heat Exchanger to transfer the heat to a secondary gas loop. The secondary gas loop is routed through the CB Thermal Sleeves out to the Charge Heat Exchanger (CHX) and back.

8 The temperature at T1 is verified to be sufficient for Platform operation.

9 Heat tracing of the molten salt piping is verified to be operational.

10 The Cold Salt Pump and the Hot Salt Pump are activated.

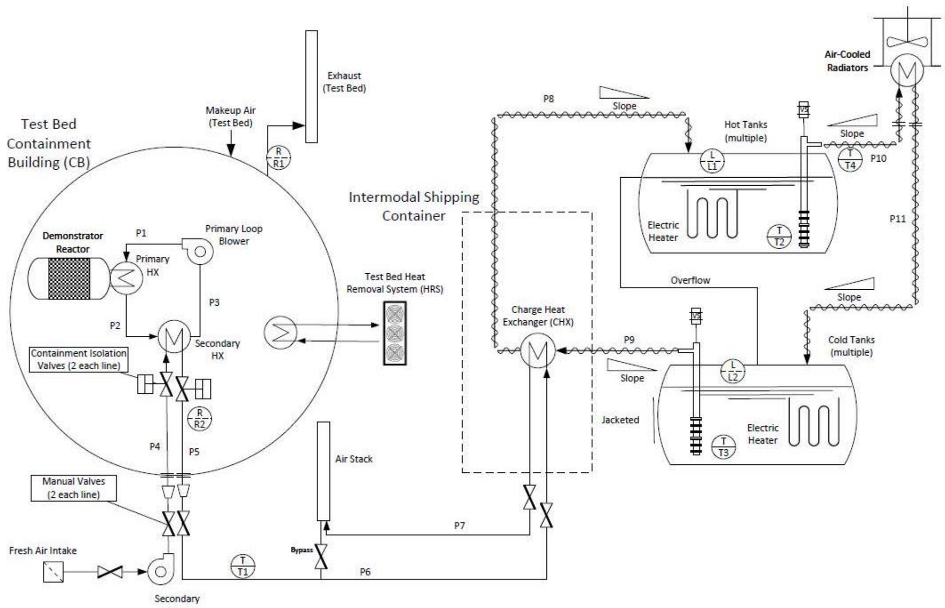

Figure 5. Integrated Startup and Operation

6.3 Nominal Operation

The following are nominal operations after the reactor has been brought to full power.

1 The Test Bed Gas Heat Exchanger transfers heated gas from the reactor through Test Bed penetrations to the Charge Heat Exchanger (CHX).

2 Heat from the reactor that is not transferred to the CHX is dissipated to the air in the CB and removed by the Test Bed Heat Removal System (HRS).

3 Cold and Hot side pumps push molten salt through the CHX and the Air-Cooled Radiator.

4 The CHX "charges" the Hot Tanks with thermal energy.

5 The air flow through the Air-Cooled Radiator is moderated to vary the heat discharged from the Hot Tanks.

6 The flow of molten salt that is circulated through the Platform heat exchangers is controlled to prevent overcharging the Hot Tanks. As the Hot Tanks become fully charged, the salt pumps continue to operate at very low flow to prevent the freezing of the molten salt within the pipelines.

6.4 Off-Normal Conditions

6.4.1 Off-Normal Operation – Release of Contamination

1 The Test Bed Containment Ventilation System (CVS) draws air from the CB and exhausts it to a stack.

2 The radiation sensor R1 at the CVS exit from the CB monitors the airborne contamination that is released to the CB from the reactor or the Charge Exchanger.

3 Additionally, the radiation sensor R2 at the exit of the Test Bed Gas Heat Exchanger detects a breakthrough of radioactive contamination to the secondary loop.

4 Upon detection of high radiation at R1 or R2, Containment Isolation Valves in series with active penetrations are closed to isolate the contamination within the CB. An active penetration is one with fluid in it. This includes the penetrations that are allocated to the Platform.

5 Heat that continues to emanate from the reactor is dissipated to the CB. Natural convection, the thermal properties of the CB walls, and a limitation on the size of the reactor keep the temperature of the CB walls within prescribed limits.

6.4.2 Off-Normal Operation – Loss of Offsite Power

1 Heat tracing of the molten salt piping keeps it from freezing even when outdoor temperatures reach -47 deg F.

2 Upon loss of offsite power, standby generators are activated to maintain power to the heat tracing.

6.4.3 Off-Normal Operation – Pump Malfunction

1 If one of the molten salt pumps malfunctions, the other pump will continue to operate for an indefinite period of time, possibly a few minutes.

2 The Hot and Cold Tanks are co-located such that overflow from one side will be routed to the other side.

6.4.4 Off-Normal Operation – Tank Leak

1 If a molten salt tank leaks, the surrounding enclosure will contain the entire content of the tank.

6.4.5 Off-Normal Operation – Molten Salt Pipe Leak

1 If a molten salt pipe leaks, the surrounding enclosure will contain the spill and drain the salt back to the attached tank.

2 The leak detection tape in the outer wall of the pipe senses the leak, alarms operators, and stops the molten salt pumps.

7 IMPACT CONSIDERATIONS

This section describes the potential impacts, both positive and negative, on the environment and other areas.

7.1 Environmental Impacts

The Platform will generate small amounts of hazardous waste. When stored and disposed properly, these wastes will have negligible impacts to the environment.

7.2 Organizational Impacts

The Platform operation is anticipated to require additional employees for construction and for operations.

7.3 Scientific/Technical Impacts

The anticipated scientific or technical impact of a successful project are as follows:

- **Operation of Reactors Integrated with Thermal Storage**: The operation of the AR-IES Platform demonstrates the integration of reactors and thermal storage. This will positively impact the reactor designers working to develop the next generation of nuclear reactors, the nuclear industry, and U.S. competitiveness in nuclear science and technology.

- **Commercialization and Improving the Institutional Knowledge**: This Platform simultaneously readies U.S. companies for commercialization of thermal storage while improving the institutional knowledge for future generations of these systems. Companies will gain insight, leading to improved operation and maintenance by demonstrating smaller versions of their reactor concept integrated with energy storage systems before scaling up to full-size commercial systems. They will also have data to validate the safety of their concept for regulators.
- **Timelines**: Licensing timelines and construction should be noticeably faster for the commercial versions of thermal storage systems that are integrated with small reactors. Additionally, the supply chain for the commercial versions of these systems will have already been exercised at the demonstration scale, making the leap to commercial components more predictable.

8 RISKS AND POTENTIAL ISSUES

The risks and potential issues associated with the development, operations or disposal of the envisioned system are as follows:

8.1 Safety Risks

Radioactivity: Hazards to workers include potential exposure to radioactive materials. The Test Bed provides SSCs serving a safety function in protecting the facility worker from these hazards. This includes features that shield personnel and equipment from radioactive shine and features that prevent or mitigate releases of radioactive contaminants from the reactor.

High Temperatures: Hazards that are normally associated with high temperatures and pressurized systems can result from postulated failure conditions in one or more components or from operational errors. The principal safety functions to protect against potential hazards are adequate cooling, control, and continued integrity of material confinement boundaries. All three may be related to a degree, depending upon the details of a given accident.

Chemical Reactions: In addition to nuclear hazards, the possibility of chemical reactions or fires also exists. The salt is a strong oxidizer.

8.2 Environmental Risks

Spills and leaks of molten salt to the ground may be damaging to wildlife and groundwater. If that's the case, then the Project needs to identify materials of environmental concern and:

- Develop strategies to prevent and mitigate spills.
- Provide for the decommissioning of the Platform

8.3 Engineering Challenges

8.3.1 Platform Not Compatible with Multiple Reactor Concepts

The reactor heat transfer mechanisms and parameters may differ for each new reactor. Differences may render integration with the Platform impossible.

8.3.2 Delivery and Melting of Solid Salt

The salt to be used as storage media will be delivered to the Platform as pourable solids. These solids will need to be added to the storage tanks and then melted for subsequent operations.

8.3.3 Salt Degradation

The salt to be used as storage media degrades when exposed to air.

8.3.4 Priming of Molten Salt Pumps

If centrifugal pumps are used to circulate molten salt, they will need to be primed in some way.

8.3.5 Freezing of Molten Salt

The molten salt may freeze in the Platform piping when the reactor is not running or the molten salt pumps quite working. Reliable electrical heat and electrical heat tracing are required to keep the salt molten.

8.3.6 Drainage of Molten Salt

Components containing molten salt must be configured for drainage at the end of pumping operations. This drives a need to factor component elevations in the design.

8.3.7 Thermal Cycling

The variable operation of the molten salt circulation will induce periodic expansion and contraction of molten salt components and their interfaces thereby creating metal fatigue and eventual cracking.

8.3.8 Inertial Forces

Inertial forces created by the flow of molten salt will act on surfaces that are perpendicular to the flow thereby creating metal fatigue and eventual cracking.

9 APPENDIX

Appendix A

Acronyms

AR-IES: Advanced Reactor Integrated Energy System

CH: Contact-Handled

COR: Code of Record

DOT: Department of Transportation

DSA: documented safety analysis

ECAR: Engineering Calculation and Analysis Report

EDMS: Electronic Document Management System

F&OR: Functional and Operational Requirements

FSAR: Final Safety Analysis Report

HVAC: Heating, Ventilation, and Air Conditioning

ID: Inside Diameter

IDD: Interface Description Document

IDEQ: Idaho Department of Environmental Quality

INL: Idaho National Laboratory

INTEC: Idaho Nuclear Technology & Engineering Center

LLW: Low-level Waste

LOTUS: Laboratory for Operation and Testing in the U.S.

LWP: Lab-wide Procedure

MARVEL: Microreactor Application Research Validation and Evaluation Project

MCP: Management Control Procedure

MCRE: Molten Chloride Reactor Experient

MFC: Materials and Fuels Complex

MMD: Major Modification Determination

NASA: National Aeronautics and Space Administration

NEPA: National Environmental Policy Act

NQA: Nuclear Quality Assurance

NRC: Nuclear Regulatory Commission

NRIC: National Reactor Innovation Center

O&MM: Operation and Maintenance Manual

PDD: Program Description Document

PFNW: PermaFix Northwest

PIE: Post-Irradiation Examination

PLN: Plan (a document type)

PPE: Personal Protective Equipment

RHLLW: Remote Handled Low-Level Waste

RPP: Radiation Protection Program

SAR: Safety Analysis Reports

SDD: System Design Description

SDS: Safety Design Strategy

SSC: System, Structure, and Component

STD: Standard (a document type)

T&FR: Technical and Functional Requirement

TEV: Technical Evaluation

TPL: Technical Project Lead

TPR: Technical Procedure (document type)

TS: Technical Specifications

TSR: Technical Safety Requirement

USE: Underground Service Entrance

WAC: Waste Acceptance Criteria

WCS: Waste Control Specialists