ARC-100 TECHNICAL SUMMARY

CLEAN TECHNOLOGY

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ABOUT THIS DOCUMENT

The ARC-100 Technical Summary describes the Canadian version of the ARC-100 Generation IV 100 MWe sodium-cooled fast neutron reactor standard plant.

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1 ARC-100 TECHNOLOGY OVERVIEW

The ARC-100 design is based upon Advanced Reactor Concepts LLC and GE-Hitachi Nuclear Energy (GEH) reactor technology that leverages the proven sodium-cooled fast reactor technology originally developed by the US Government Department of Energy.

The ARC-100 reactor incorporates operating, technical, and safety experience accumulated from a historical worldwide fleet of 20 fast neutron reactors in existence since the 1950s with over 450 reactor-years of operating experience.

The ARC-100 advanced small modular reactor combines experience from previous sodium-cooled fast reactors with modern design improvements to meet industry and public expectations for nuclear power generation for a net-zero economy.

The ARC-100 offers 100 Megawatts of stable electrical power, enough to support 75,000 households.

ARC-100 advantages:

Proven Design
The design foundation of the ARC-100 is rooted in the United States Department of Energy Experimental Breeder Reactor-II (EBR-II) program, which operated for over 30 years from 1964-1994. As a result, research and development is complete, with engineering underway to enable early deployment.

Enhanced Safety
The inherent safety features and passive decay heat removal systems enable the ARC-100 reactor to transition to a safe state without operator intervention; safety features rely on the laws of physics – the ultimate backup safety system.

Economical
The levelized cost of electricity is estimated to be below conventional nuclear and competitive with renewable energy sources.

Sustainability
The ARC-100 operates on a 20-year refueling cycle that significantly reduces the quantity of long-term waste.

Versatility
The ARC-100 is suitable for a wide range of applications. From clean grid electricity to industrial heat, medical isotope generation, hydrogen production, and load following to support renewable energy sources (wind/solar).

Scalability
The ARC-100 is a scalable small modular reactor – several units can be grouped together to create larger generation hubs. Its components will be factory-built, assembled into modules at a fabrication facility, and delivered to the site.

Artistic renderings of the ARC-100 standard plant site layout are shown in Figure 1-1 below.

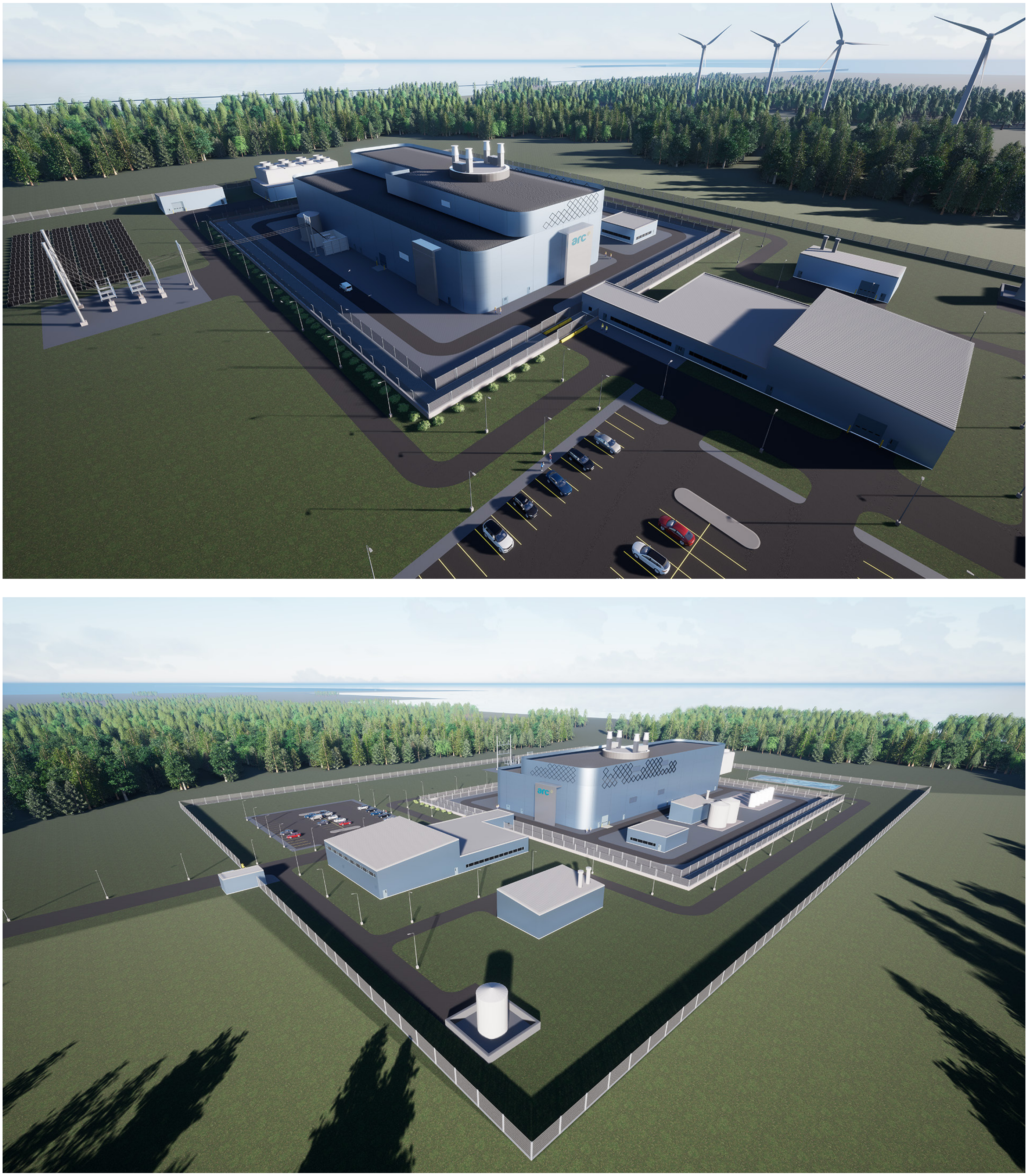


Figure 1-1 ARC-100 Aerial Views of Standard Plant Site Layout

1.1 Sodium-Cooled Fast Reactor Technology

Liquid metal fast reactors use liquid metal as the reactor coolant in place of the water that is typically used in commercial nuclear power plants.

Fast reactors employ a fast neutron spectrum, meaning that neutrons can cause fission without having to be slowed down first, as is required for water-cooled reactors. The fast neutron spectrum allows fast reactors to use both fissile materials and reprocessed spent nuclear fuel to produce heat.

Liquid sodium metal has been chosen as the coolant for the ARC-100 reactor due to its high boiling point of 883°C which allows for a core outlet coolant temperature of 510°C, and a 373°C margin of safety to boiling. Liquid sodium metal allows the ARC-100 to operate at higher temperatures and lower pressures than current reactors while improving both the thermal efficiency of the reactor for electricity generation and maintaining a large safety margin during accident transients.

Pool or loop configurations exist in sodium-cooled fast reactor technology. A pool-type configuration, in which the primary coolant is contained in the reactor vessel, has been chosen for the ARC-100 reactor due to the multiple safety and operational benefits of this design. Figure 1-2 illustrates a sodium-cooled fast reactor pool design:

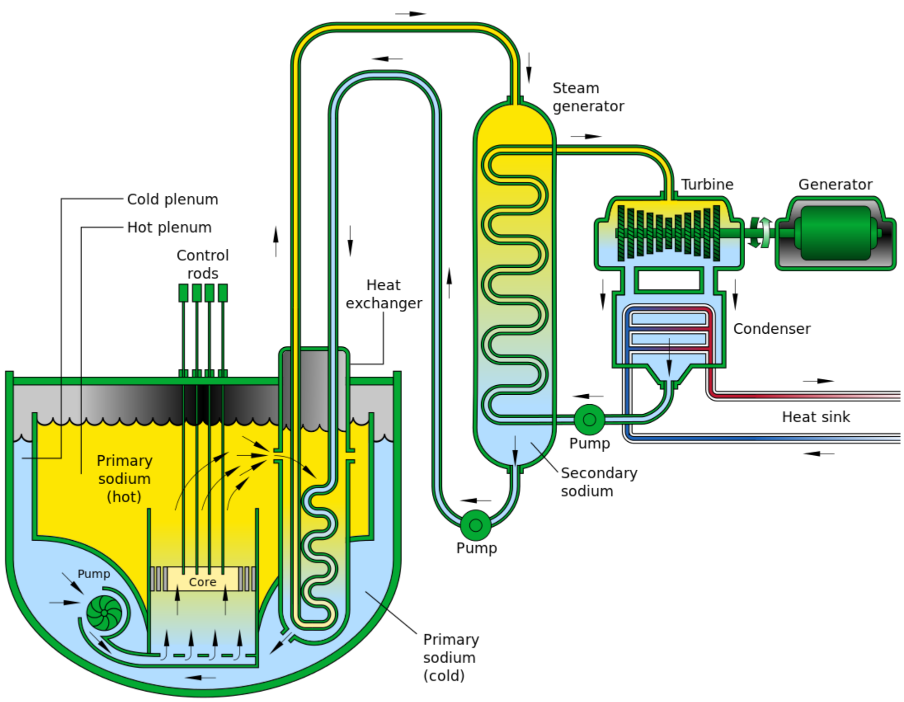


Figure 1-2: Sodium-Cooled Pool-Type Fast Reactor

In their independent report, "Sodium-Cooled Fast Reactor System Safety Assessment", the Generation IV International Forum noted that *"With more than 20 reactors built and in operation around the world and combining nearly 400 reactor years of operation, sodium-cooled fast reactors benefit from extensive design and operating experience feedback".* Generation IV sodium-cooled fast reactors incorporate significant technology innovations, reducing capital costs through a combination of a simple configuration, the use of advanced fuels and materials, and refined safety systems.

1.2 The ARC-100 Reactor

The ARC-100 reactor is a 100 Megawatts electric/286 Megawatts thermal Generation IV advanced small modular reactor utilizing sodium-cooled fast reactor technology.

The ARC-100 is a commercial, grid-scale evolution of the Experimental Breeder Reactor-II (EBR-II) design that was built and operated at the National Reactor Testing Station at Idaho National Laboratory. The EBR-II achieved criticality in 1965, operated successfully for 30 years, and was used to test fast reactor fuels and materials for future sodium-cooled fast reactors.

The ARC-100 design is the next evolution of the sodium-cooled fast reactor technology developed in the US Department of Energy fast reactor programs, as illustrated in Figure 1-3 below.

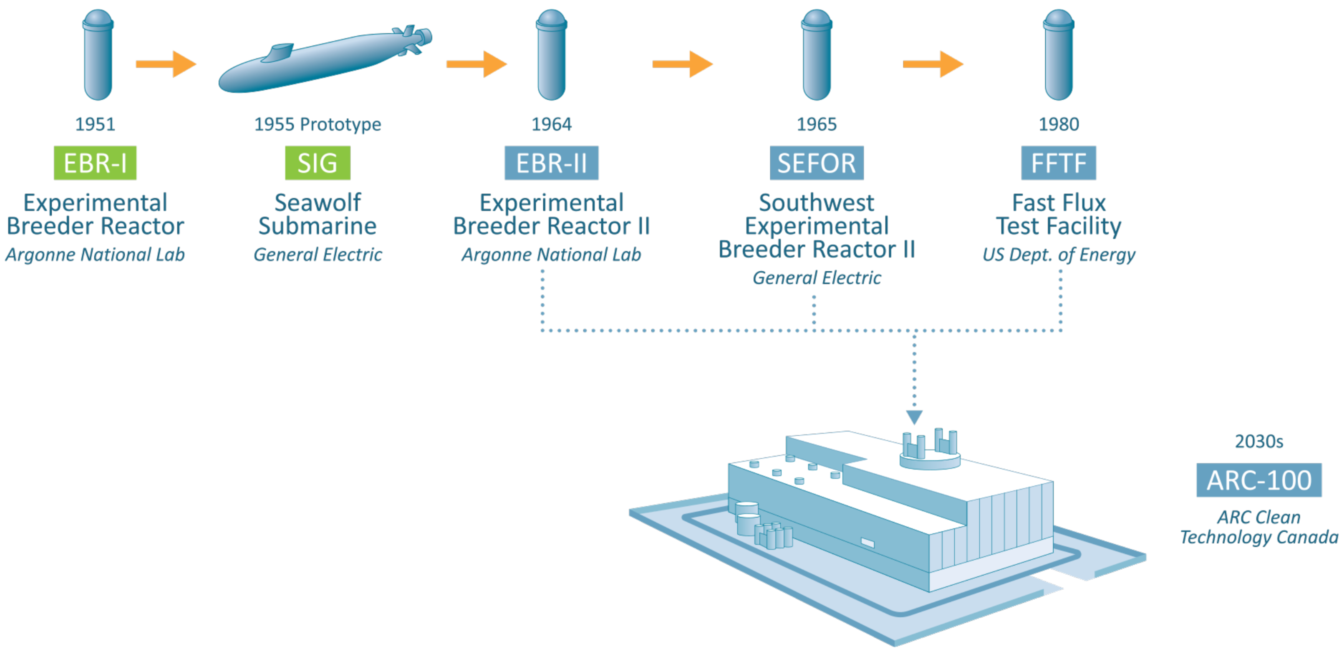


Figure 1-3: ARC-100 Evolutionary Path

At 100 Megawatts electrical and 286 megawatts thermal, the ARC-100 design is a 5x scale up of the 20 Megawatts electrical output of the EBR-II, while staying within the knowledge base of the Fast Flux Test Facility's 400 Megawatts thermal reactor.

Major Technical Parameters

Reactor type	Sodium cooled fast reactor (pool type)
Thermal/electrical capacity	286MWth / 100MWe
Primary circulation	Forced circulation
NSSS operating pressure (primary/secondary)	Non-pressurized
Core inlet/outlet coolant Temperature	355°C / 510°C
Fuel type/assembly array	Metal fuel (U-Zr alloy) based on enriched uranium
Number of fuel assemblies in the core	99
Fuel enrichment	Avg. 13.1%
Core discharge burnup	77 gigawatt-days/metric ton
Fuel Cycle	20 years
Reactivity control mechanism	Control rods
Approach to safety systems	Passive, diverse, redundant
Design life	60 years
Site footprint (single unit)	54,000 m2
Reactor pressure vessel height/diameter	15.6 m / 7.6 m
Distinguishing features	• Inherent reactor safety with passive, diverse and redundant decay heat removal • Core lifetime of 20-years without refuelling

1.3 Benefits of the ARC-100 Reactor

Safety Benefits

- The ARC-100 pool-type design ensures that the primary coolant, reactor core, primary pumps, reactor components, and intermediate heat exchangers are all contained within the main reactor vessel.
- The large mass of primary sodium provides greater heat capacity (larger thermal inertia) allowing a longer grace period during temperature excursions.
- Natural circulation in the sodium pool transfers residual decay heat from the core, ensuring long term passive safety during temperature excursions.
- The inherent safety characteristics of the metallic-fueled fast spectrum core allow the reactor to reliably achieve a self-limiting reactivity in addition to the primary and secondary shutdown devices.
- The elimination of piping penetrations below the top of the reactor vessel precludes loss-of-coolant accidents due to pipe failures.
- A guard vessel enclosing the reactor vessel ensures that the fuel will always remain immersed in sodium.
- An air gap between the exterior of the guard vessel and the containment wall provides a redundant, independent means to remove residual decay heat by conduction and radiative heat transfer.

Operational benefits

- Simple process systems with fewer components result in reduced capital, operating, maintenance, and decommissioning costs.
- Spent fuel storage within the reactor vessel eliminates the need for a separate spent fuel storage pool.

In addition to these innovative design features, the experience and feedback developed by the Generation IV International Forum combined with historical data acquired from the EBR-II and the Fast Flux Test Facility reactors, provide an in-depth knowledge base for the operation, performance of structures, systems, components, and materials for the ARC-100 reactor design.

1.4 International Licensability

To ensure international licensability, the basis for the design of the ARC-100 standard plant uses experience from a proven approach by a Canadian water-cooled reactor technology, with reactors deployed in several countries around the world.

This approach is based on meeting Canadian regulatory requirements and international best practices:

Safety approach
The ARC-100 safety philosophy and objectives are based on the safety approach recommended by the Generation IV International Forum for sodium-cooled fast reactors. This safety approach utilizes the International Atomic Energy Agency's safety standards in establishing safety goals and criteria specific to sodium-cooled fast reactor technology. It aims to achieve improved operational safety and reliability, a reduced likelihood and degree of reactor core damage, and virtually eliminate the need for off-site emergency response.

Safety design requirements
A comprehensive set of safety design requirements have been established for the ARC-100 using insights from the International Atomic Energy Agency's safety design requirements for nuclear power plants, the Generation IV International Forum safety design criteria, and the Canadian Nuclear Safety Commission's regulatory design requirements.

Environmental impact, radiation protection, and decommissioning
The ARC-100 design incorporates experience from previously operated sodium-cooled fast reactors to minimize radiation source terms during normal operation and to plan for the types and quantities of radioactive waste that will be produced during decommissioning. The As Low As Reasonably Achievable (ALARA) principle has been used to optimize the design for radiation and environmental protection. The ARC-100 design also minimizes the impact on the environment from non-radiological emissions from plant operation.

Site evaluation
The ARC-100 standard plant has been designed for a generic set of environmental conditions, suitable for multiple sites around the world. The standard plant design minimizes the effects of the local environment on the ability of the ARC-100 to operate within a defined safe operating envelope.

Site-specific deployment
A site-specific deployment of the ARC-100 can accommodate local regulatory requirements with limited changes to the standard plant design.

1.5 Safety Goals

The ARC-100 design has the following safety and reliability goals:

1. The ARC-100 plant will excel in operational safety and reliability by minimizing the occurrence of operational events that could cause a forced outage thereby improving worker safety and reducing routine emissions that could affect workers or the public.
2. The ARC-100 plant design features will create high confidence that the possibility and degree of core damage accidents will be lower than for previous generation reactors.
3. The ARC-100 plant will further reduce the need for off-site emergency response by improving the capability of plant safety features to manage and mitigate the consequences of severe plant conditions.

1.6 Power Generation Objectives

The ARC-100 is designed to have a core thermal power output of 286 Megawatts thermal and a net electrical output of 100 Megawatts electric. The design is based on achieving a target lifetime capacity factor of greater than 90%.

The ARC-100 design provides for flexible operation, allowing the reactor to load follow customer demand and enabling the integration of renewable energies into the grid without sacrificing power reliability and stability.

1.7 Reliability and Availability Objectives

The ARC-100 plant design provides high confidence of achieving a lifetime capacity factor of greater than 90% over its full 60-year operating life.

Operating reliability is improved through implementation of the following design features on an integrated basis:

- Redundant divisions in some systems facilitate on-line maintenance and refueling once every 20 years. This minimizes time lost due to unplanned outages and reduces the duration of planned outages.
- The plant is designed for an annual forced loss rate (i.e., unplanned shutdowns or load reductions) of less than 1%.
- System design improvements are incorporated to address feedback from operational experience.
- The system design uses proven technology from previous sodium-cooled fast reactor designs.

1.8 Operation and Maintenance

The operation of the ARC-100 plant integrates regular short maintenance outages and a longer maintenance and refueling outage which occurs once every 20 years.

Most of the structures, systems, and components in the ARC-100 are designed to have a minimum design life of 60 years. Where components do not have a 60-year design life, the plant design enables component replacement.

1.9 Construction

The overall construction schedule is 34 months, with the time between first nuclear concrete and fuel load taking only 23 months. An example of the construction schedule is provided in Figure 1-4.

The ARC-100 design facilitates the use of prefabricated modules for some systems. For example, the design of the reactor vessel enables its installation as factory-fabricated modules within the cylindrical concrete containment structure. This module contains all pre-installed core internal components, excluding fuel assemblies and reactivity drive mechanisms.

The small layout footprint of the ARC-100 plant, and the use of prefabricated modules, results in smaller construction crew sizes and facilitates temporary construction facilities.

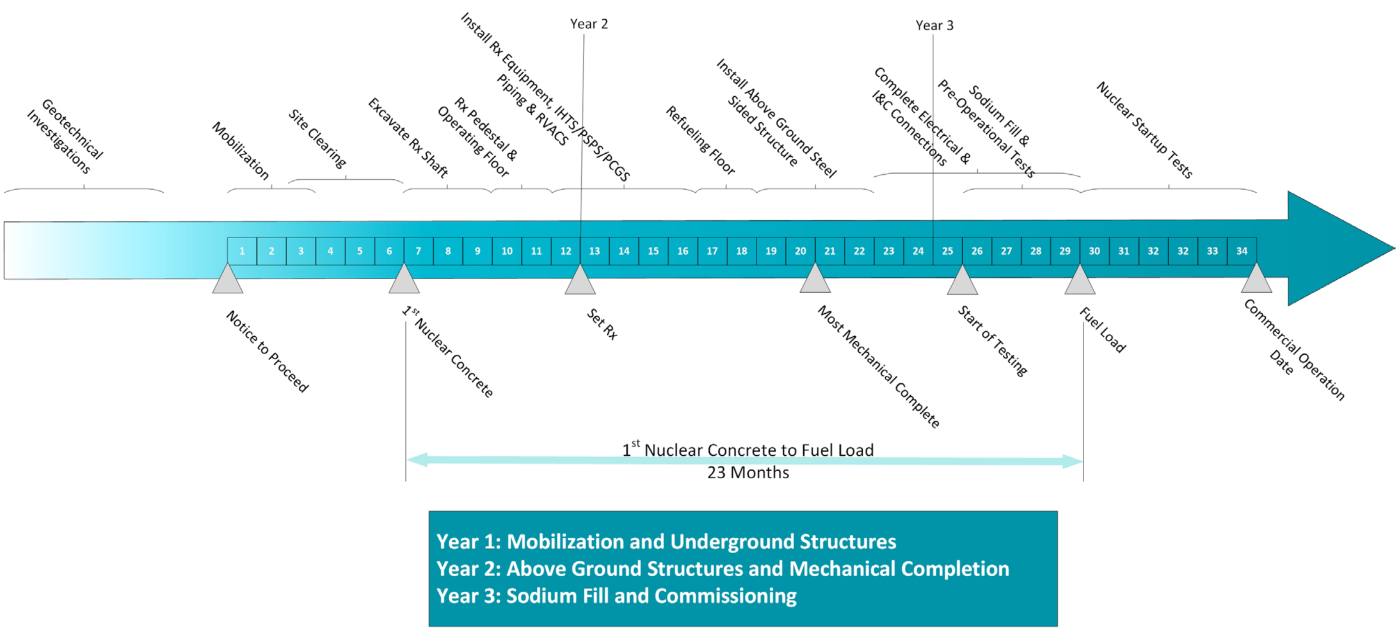


Figure 1-4: Example Construction Schedule

2 PLANT LAYOUT

The plant layout for the ARC-100 is based on a typical single unit arrangement for a nuclear power plant. The major buildings and structures associated with the overall site arrangement are shown in Figure 2-1 and are listed as follows:

Nuclear Steam Supply
Reactor Building (Containment)
Reactor Auxiliary Building
Service Building with Main Control Room
Radioactive Waste & Maintenance Building
Steam Generator and Auxiliaries Enclosure
Secondary Control Building
Spent Fuel Storage

Balance of Plant
Turbine Generator Hall
Turbine Generator Auxiliaries
Training Center/Office
Warehouse
Water/Sewer
Fire Water Storage and Pumps
Switchyard
Cooling Towers
Other plant services

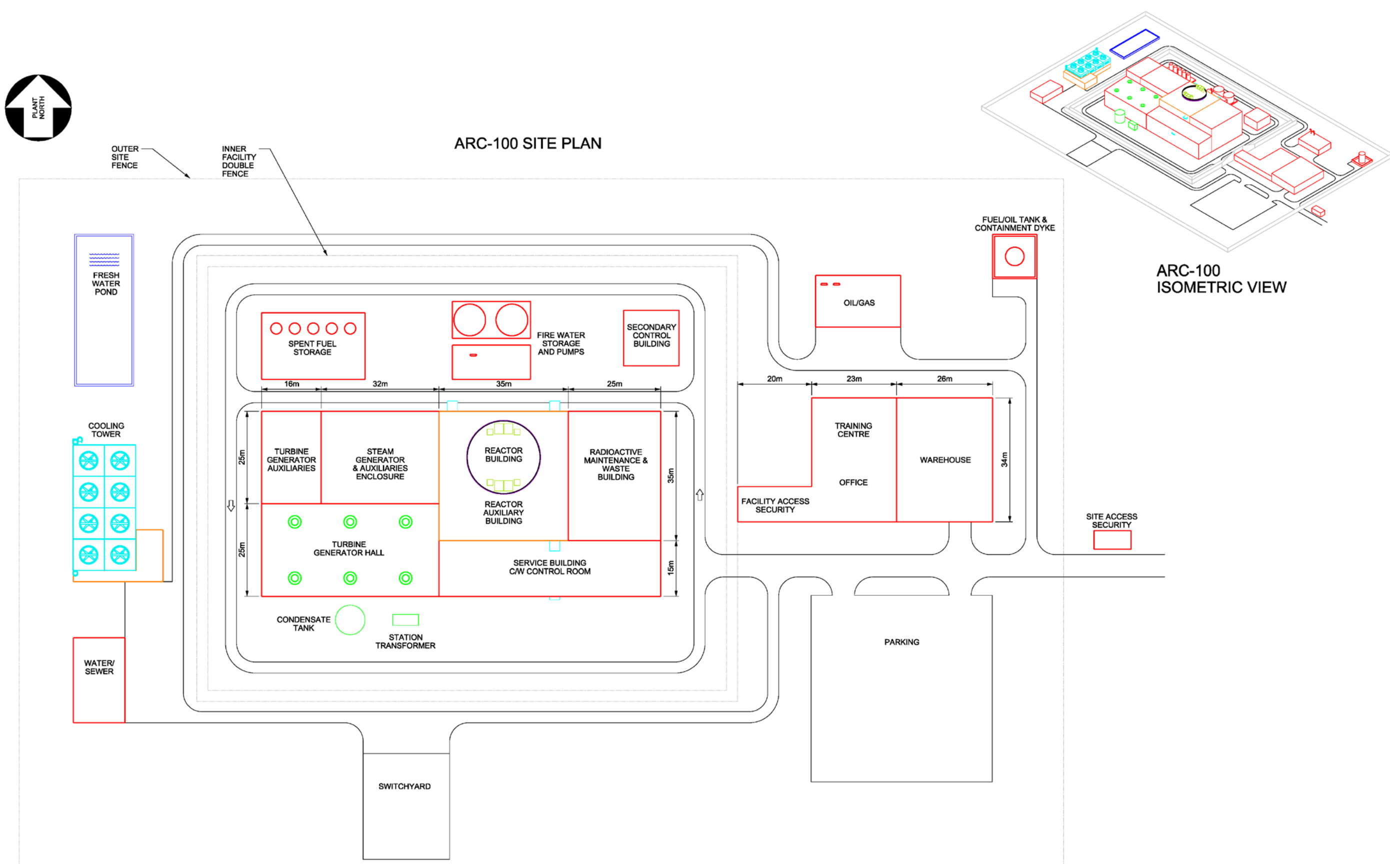


Figure 2-1 ARC-100 Site Plan

2.1 Layout Approach

In comparison to past generations of traditional water-cooled nuclear power plants, the limited number and size of systems in the ARC-100 enables a reduced plant layout. The optimized layout results in reduced design effort, capital cost, construction, operations and maintenance considerations, and space allocation for waste management.

The systems identified as "important to safety" are consolidated in buildings that are qualified for a design basis earthquake. The layout arrangement optimizes the placement of external walls to protect against the effects of a design basis tornado.

The nuclear systems, safety systems, and the safety support systems are housed in the reactor building, the reactor auxiliary building, the service building, and the steam generator and auxiliaries enclosure. Physical separations within these buildings minimize the potential for common cause events that could impact redundant components and divisions at the same time.

A sectional view of the plant layout is illustrated in Figure 2-2.

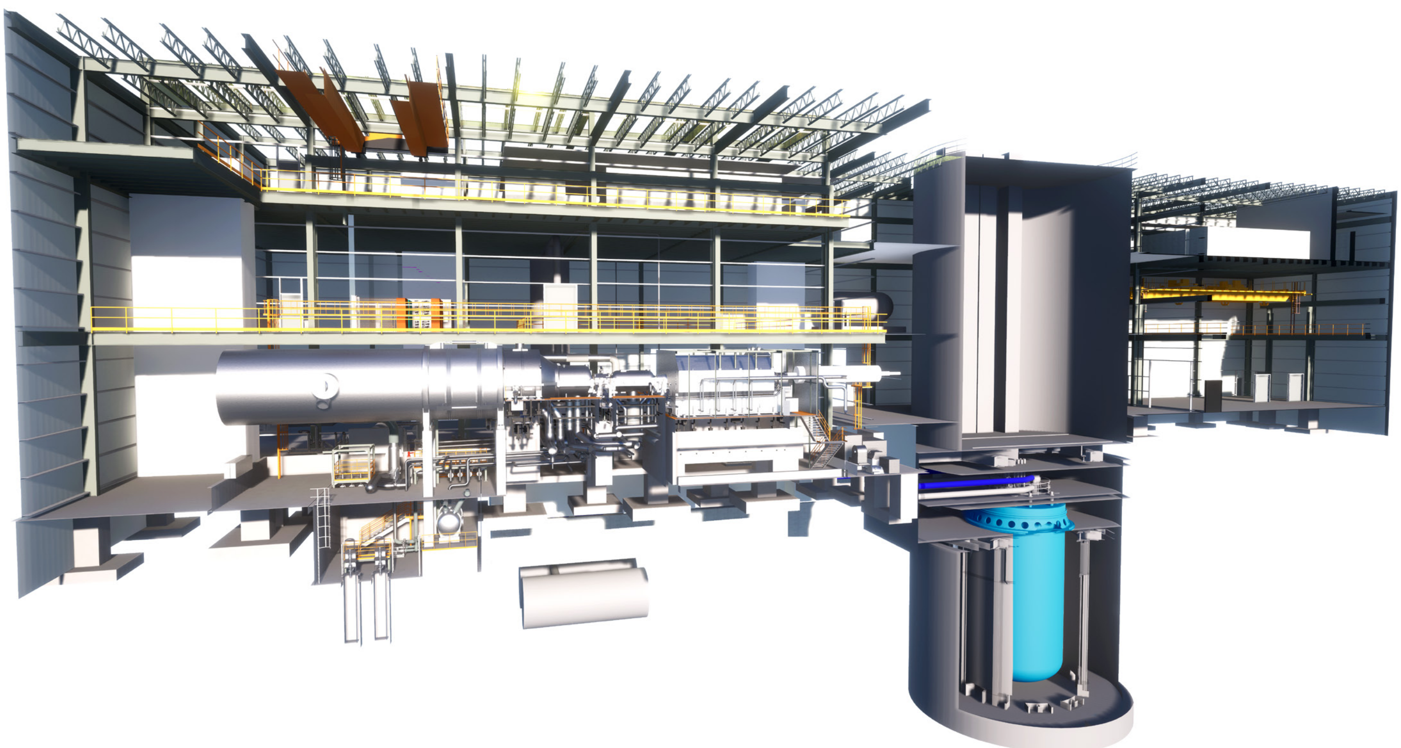


Figure 2-2 ARC-100 Section View

The main control room in the service building is positioned so that it would be highly unlikely for a common cause event to disable both the main and secondary control rooms simultaneously. A seismically qualified route is provided for the operator to move from the main control room to the secondary control room in the event the main control room becomes unavailable.

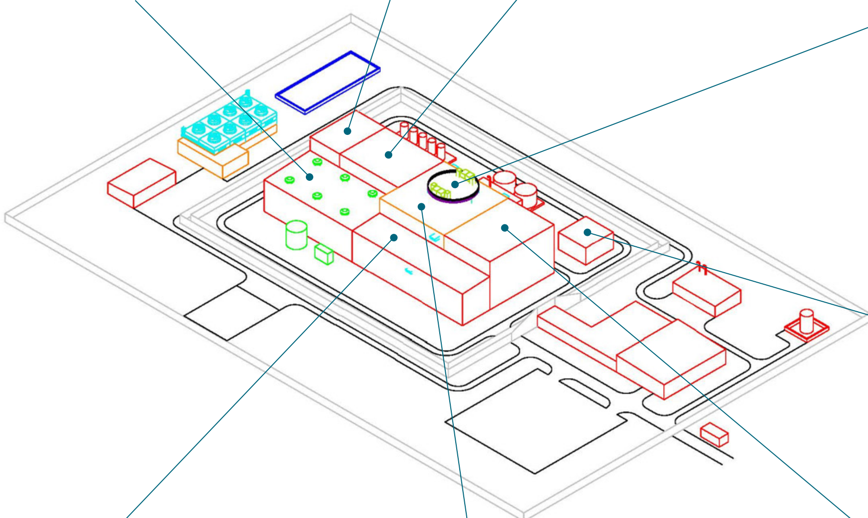
Turbine Generator Hall
The turbine generator hall houses the turbine generator. The turbine generator auxiliary systems, condenser, and condensate and feedwater systems are housed in the turbine generator hall and the adjacent turbine generator auxiliaries structure.

The wall between the turbine generator hall and the steam generator and auxiliaries enclosure is designed to withstand any event where a turbine blade failure could occur.

Adjacent Turbine Generator Auxiliaries Structure
(see turbine generator hall, left)

Steam Generator and Auxiliaries Enclosure
The steam generator and auxiliaries enclosure is designed to withstand a design basis earthquake, tornado conditions, and other site hazards. It houses the steam generator system and intermediate heat transport system.

Reactor Building
The reactor building, which acts as the containment boundary, houses the reactor vessel, guard vessel, the Ex-vessel transfer machine, the collector cylinder for reactor vessel auxiliary cooling system, and the piping for the intermediate heat transfer system, primary sodium system, and direct reactor auxiliary cooling systems. It is a cylindrical concrete containment structure with the reactor vessel located below ground level and an operating deck above the reactor vessel top plate. The containment structure is designed to withstand a design basis earthquake, tornado conditions, other site hazards, and aircraft crash impact. The containment structure provides an environmental boundary, biological shielding, and the final physical barrier for containing radioactive material.



Secondary Control Building
The secondary control building is designed to withstand a design basis earthquake, tornado conditions, and other site hazards. It houses the secondary control room and technical support center.

Service Building with Control Room
The service building is a multi-story structure that is designed to withstand a design basis earthquake, tornado conditions, and other site hazards. It houses systems related to controlling plant operation, such as the main control room.

Reactor Auxiliary Building
The reactor auxiliary building is a multi-story structure that is designed to withstand a design basis earthquake, tornado conditions, and other site hazards. It surrounds the reactor building and houses parts of systems located within the reactor building. It also accommodates the piping and ducts for the intermediate heat transfer system, direct reactor auxiliary cooling system, and the reactor vessel auxiliary cooling system.

Radioactive Maintenance and Waste Building
The radioactive maintenance and waste building is a multi-story structure that is connected to the reactor building by a transfer chamber for movement of fuel assemblies, reactor components and personnel. The radioactive maintenance & waste building houses facilities and services for solid and liquid waste management along with maintenance and operation of the plant.

Figure 2-3 ARC-100 Building Descriptions

3 NUCLEAR SYSTEMS

The nuclear steam supply system of the ARC-100 is shown on the left-hand side of Figure 3-1 and includes the following systems:

- Reactor Core and Fuel Assemblies.
- Reactor Control System.
- Reactor Vessel System, consisting of a Reactor Vessel shell, core internal structures, top plate, and Guard Vessel.
- Heat Transport and Auxiliary System consisting of the Primary, Intermediate, and Steam Generator Systems.
- Passive Emergency Core Cooling and Heat Removal System consisting of the Direct Reactor Vessel Auxiliary Cooling System (DRACS) and Reactor Vessel Auxiliary Cooling System (RVACS).
- Containment System.
- Fuel Handling and Storage System, consisting of an In-Vessel Transfer Machine (IVTM), spent fuel storage locations within the Reactor Vessel shell, an intra-building fuel transfer cask, and dry spent fuel storage modules.

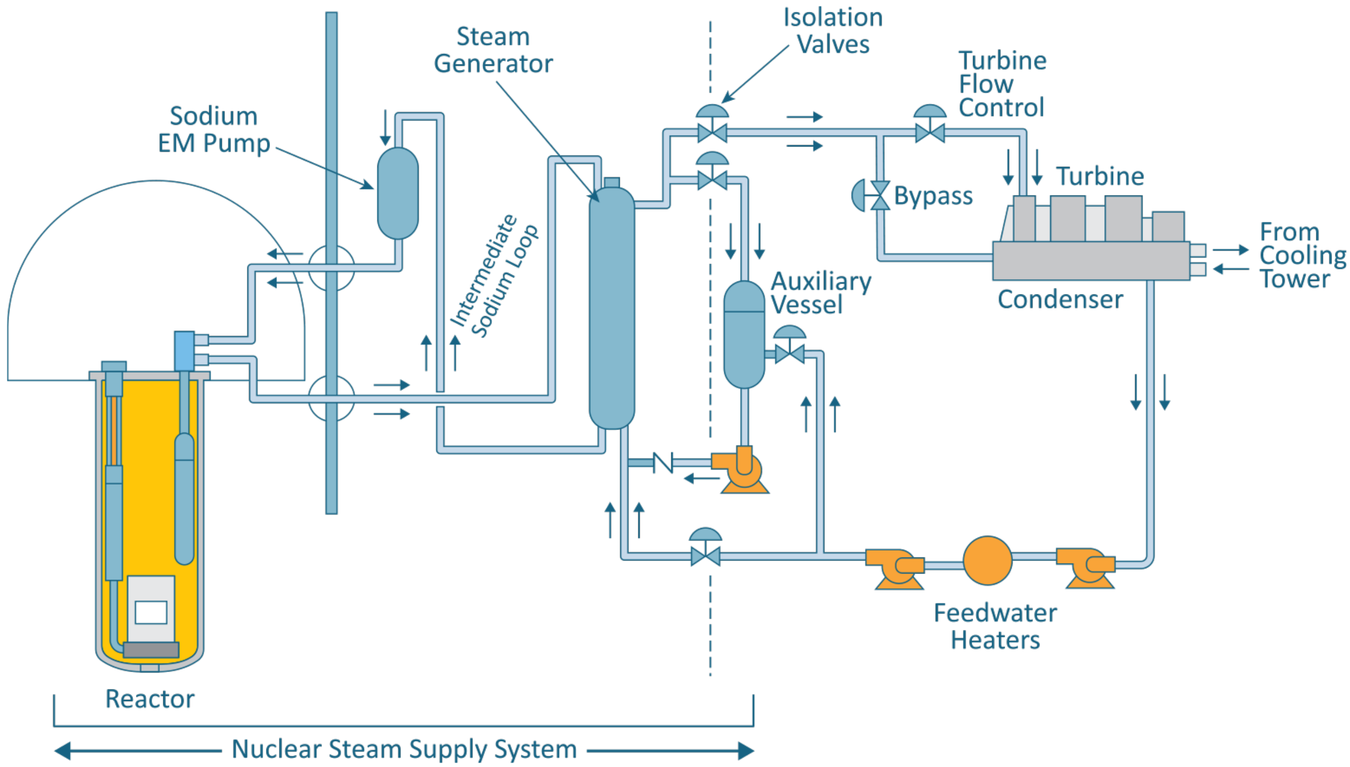


Figure 3-1 ARC-100 Nuclear Systems Schematics

3.1 Reactor Core and Fuel Assemblies

The ARC-100 core consists of fuel-containing driver assemblies, successively surrounded by steel reflector assemblies and shield assemblies. Fuel pins within the driver assemblies each contain a generous gas plenum to capture fission gases. The core is divided into inner, middle, and outer core zones to flatten the radial power distribution. Figure 3-2 shows a color-coded cross section schematic of the ARC-100 core:

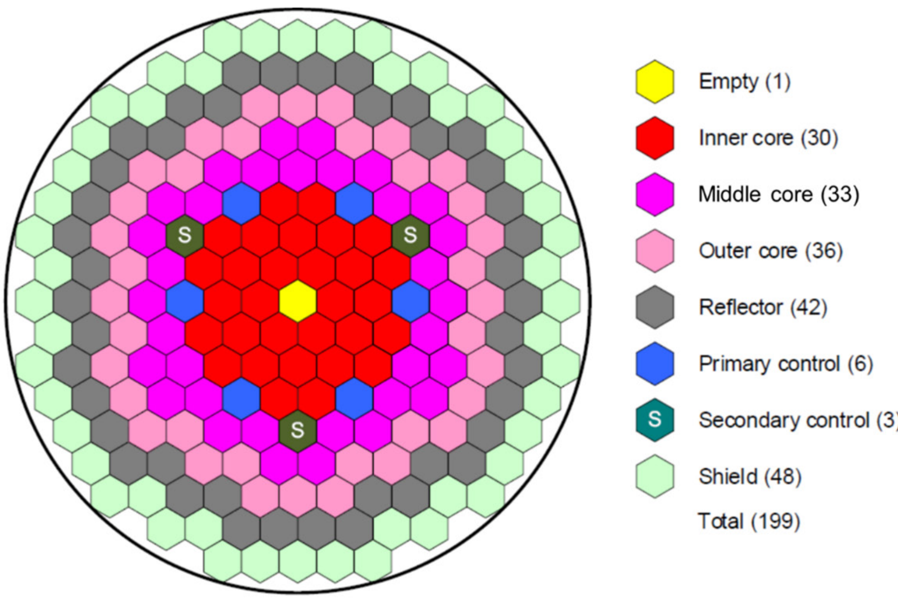


Figure 3-2: Color-coded cross section schematic of the ARC-100 core

The ARC-100 design uses a U-10%Zr (Uranium with 10 wt % Zirconium) sodium-bonded binary metallic fuel with an average uranium enrichment of 13.1 wt% U-235.

The maximum enrichment will be less than 20 wt% in compliance with the International Atomic Energy Agency requirements for High Assay Low Enriched Uranium.

A generic fuel pin is shown in Figure 3-3.

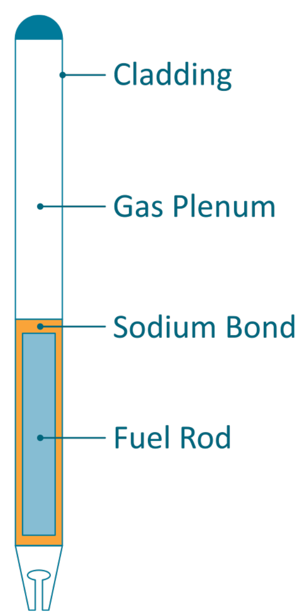


Figure 3-3 Schematic of a metal fuel pin, representative of ARC-100 Fuel

A typical ARC-100 fuel assembly is shown in Figure 3-4.

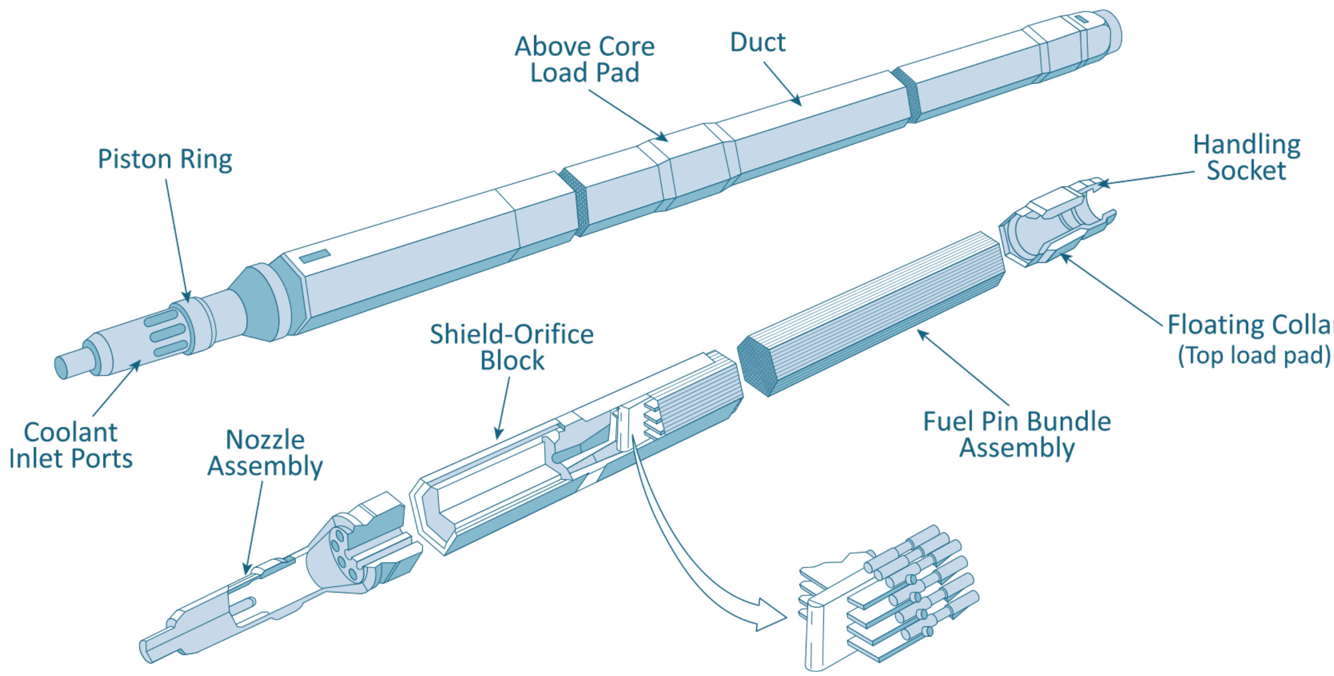


Figure 3-4 Schematic of typical ARC-100 Fuel Assembly

The U-10%Zr (Uranium with 10 wt % Zirconium) sodium-bonded binary metallic fuel has a low operating centerline temperature that provides a large safety margin to fuel centerline melting during postulated accident scenarios. The inherent safety features and performance characteristics that support passive heat removal, are conducive to a refueling cycle of 20 years and meet International Atomic Energy Agency requirements for proliferation resistance.

The ARC-100 fuel is based on the proven performance of metallic fuel in the EBR-II.

99 fuel assemblies containing 217 fuel pins each are placed inside the reactor core within the reactor vessel and remain in place for 20 years. During refueling, the irradiated fuel assemblies are transferred to the spent fuel storage racks within the reactor vessel and new fuel assemblies are loaded into the core.

3.2 Reactor Control Systems

The ARC-100 core employs active and passive reactivity control systems:

Control Rod System
The control rod system serves to start up the reactor and maintain reactor power at the demand output by compensating for the reactivity effects of the fuel burnup and axial growth of the metal fuel. The reactivity associated with uncertainties in criticality and fissile loading is also accommodated by the control rod system. This system consists of six control rods with sufficient reactivity worth to bring the reactor from any operating condition to cold subcritical from full power operating position. Any operating condition includes an overpower condition combined with a reactivity fault. The control rods are designed to drop into the core by gravity when demanded to rapidly shut down the reactor.

Shut-off Rod System
The shut-off rod system consists of three shut-off rods that are normally poised above the top of the fuel assemblies. In response to a reactor trip, these shut-off rods drop into the core under gravity to shut down the reactor from any operating condition to the cold shutdown condition.

Inherent Negative Reactivity System
The inherent negative reactivity system provides inherent safety through negative reactivity feedback whenever the temperature in the core increases. The faster the core temperature rises, the greater the negative reactivity. The inherent negative reactivity system can also shut down the reactor for added redundancy.

3.3 Reactor Vessel System

The reactor vessel design is based on established pool-type sodium-cooled fast reactors where a pool of liquid sodium is contained within the reactor vessel and top plate. The reactor vessel, the reactor top plate, and mounted components, such as the rod drive mechanisms, intermediate heat exchangers, and the direct reactor auxiliary cooling system heat exchangers form the primary system boundary. This primary coolant boundary serves as the coolant loop for the primary heat transport system. Figure 3-5 shows a 3-D model of the reactor vessel and Figure 3-6 is a representation sketch of the reactor vessel system.

The reactor vessel is enclosed within the guard vessel, which serves as a backup leak jacket. The guard vessel also serves as the heat transfer surface for the reactor vessel auxiliary cooling system.

The reactor vessel is filled with liquid sodium under an argon cover gas blanket which is maintained at slightly above atmospheric pressure. All access to the fuel and various components within the reactor vessel is from the top of the reactor, eliminating all penetrations of the pressure retaining sections of the reactor vessel below the top plate.

The low operating pressure, elimination of penetrations below the reactor top plate, and the double vessel design virtually eliminates the possibility of a Loss-of- Coolant Accident (LOCA) that has challenged the design of other reactor technologies (e.g., water-cooled reactors).

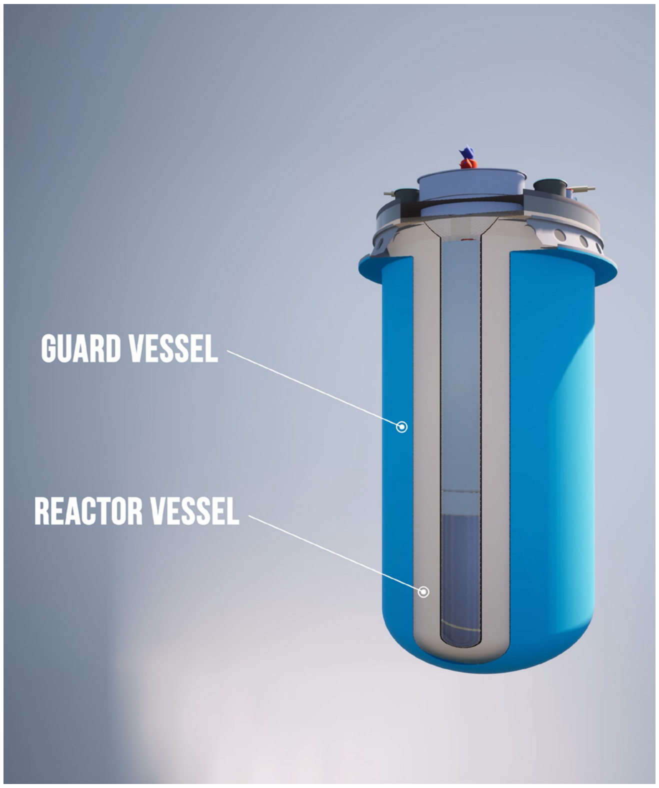


Figure 3-5 ARC-100 3-D Model Reactor Vessel

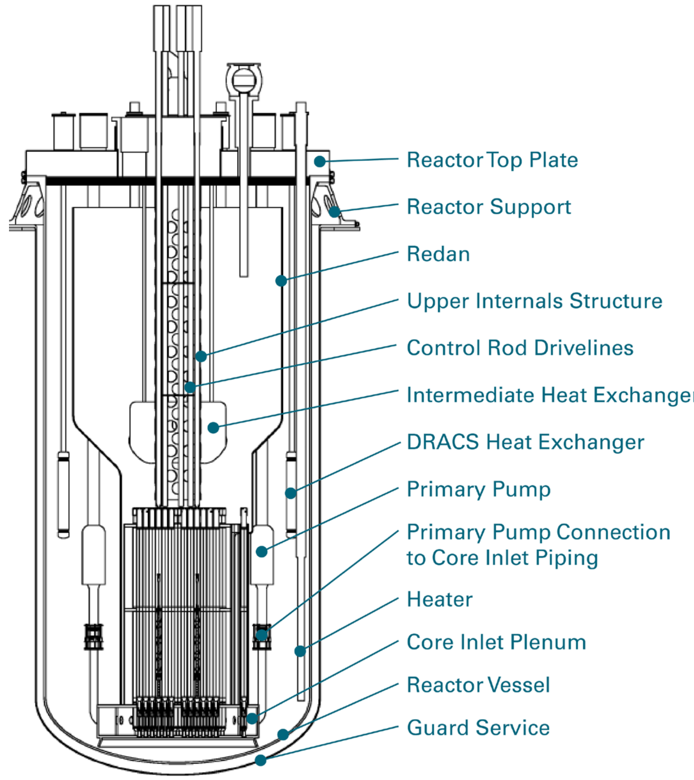


Figure 3-6 ARC-100 Reactor Vessel System

3.4 Heat Transport and Auxiliary Systems

Heat transport from the reactor core to the ultimate heat sink is performed via:

Primary Heat Transport System
Electromagnetic pumps located within the reactor vessel are used to circulate the primary sodium which carries the fission heat from the core to the intermediate heat exchangers and recirculates the primary sodium through the reactor core.

Intermediate Heat Transport System
The intermediate sodium is circulated in the two intermediate heat transport loops by electromagnetic pumps to transport heat from the secondary side of the intermediate heat exchangers to the steam generator.

Steam Generator
Steam is produced in the secondary side of the steam generator to transfer heat from the two intermediate heat transport system loops and drive the turbine generator to produce electricity. The intermediate heat transport system and the steam generator system provide heat removal during normal operation.

3.4.1 Primary Heat Transport System

The primary heat transport system is contained within the reactor vessel and is the means for transferring fission heat from the reactor core to the intermediate heat transport system as illustrated in Figure 3-7. The submersible primary electromagnetic pumps located in the cold pool at the outside of the reactor vessel pull primary sodium from the cold pool and pump it through the reactor core. While traveling through the reactor core, the cold primary sodium picks up the fission heat from the reactor core and transfers it into the primary sodium hot pool located above the reactor core. Primary sodium from the hot pool is then drawn through the shell side of the intermediate heat exchangers releasing the fission heat from the primary heat transport system into the intermediate heat transport system.

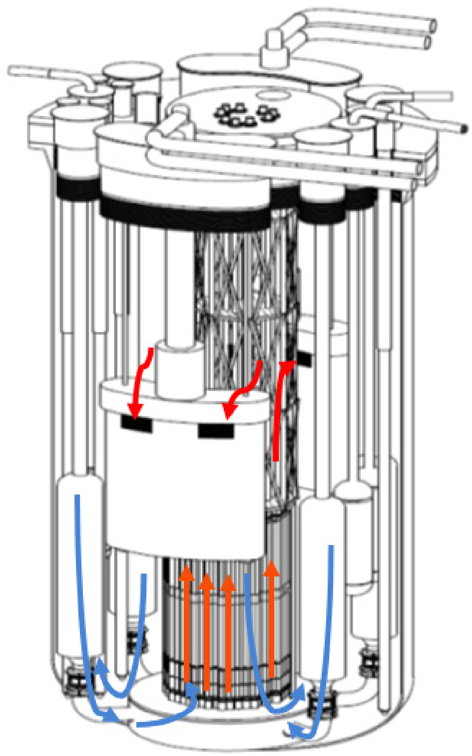


Figure 3-7 Primary Heat Transport System

3.4.2 Intermediate Heat Transport System

The intermediate heat transport system is the sodium fluid system for transporting reactor heat from the intermediate heat exchangers to the steam generator. It consists of two piping loops between the intermediate heat exchangers located in the reactor vessel, and the steam generator. Each piping loop includes an electromagnetic pump and permanent magnet flowmeters in the cold leg.

The system also includes instrumentation for detecting steam generator tube leaks, and a rupture disc driven pressure relief line which protects the steam generator shell, the intermediate piping, and the intermediate heat exchangers from overpressure. The steam generator, the sodium dump valve, and the intermediate sodium processing system are located in the steam generator and auxiliaries enclosure. Figure 3-8 shows a simplified version of the intermediate heat transport system.

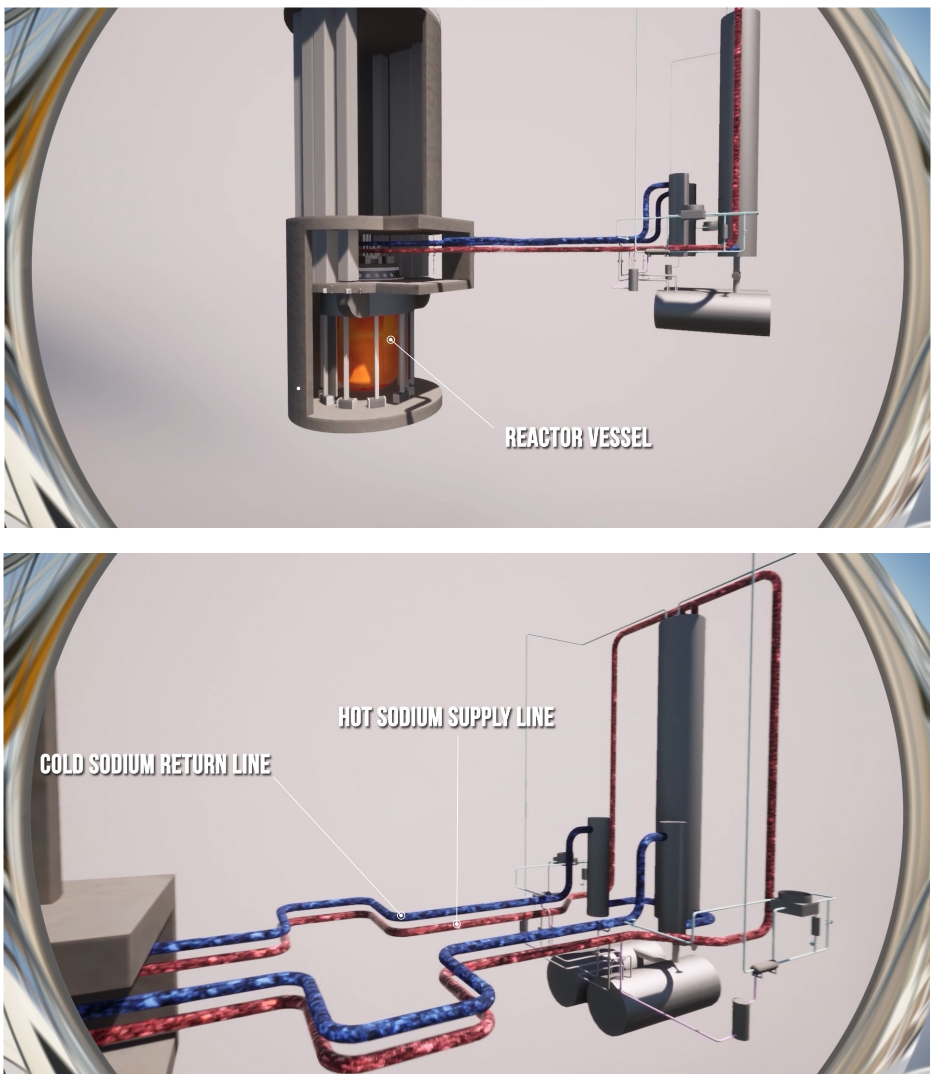


Figure 3-8 Intermediate Heat Transport System

3.4.3 Steam Generator System

The steam generator is a helical coil, single wall tube, vertically oriented sodium-to-water counter-flow shell-and-tube exchanger. It provides the interface for the intermediate sodium flowing in from the intermediate heat transport system to heat the water to generate superheated steam for the steam turbine plant. The intermediate sodium is distributed through the shell side of the steam generator while the water flows through the helical coil tube bundles. The steam generator includes a cover gas space in the upper head to accommodate the intermediate sodium level changes due to the intermediate sodium thermal expansion and pump transients.

The steam generator system is equipped with isolation valves that close on demand to isolate the steam generator from its feedwater system. The turbine generator and dump valves open on demand to drain the water and steam inventories from the steam generator. The steam generator and associated auxiliaries are shown in Figure 3-9.

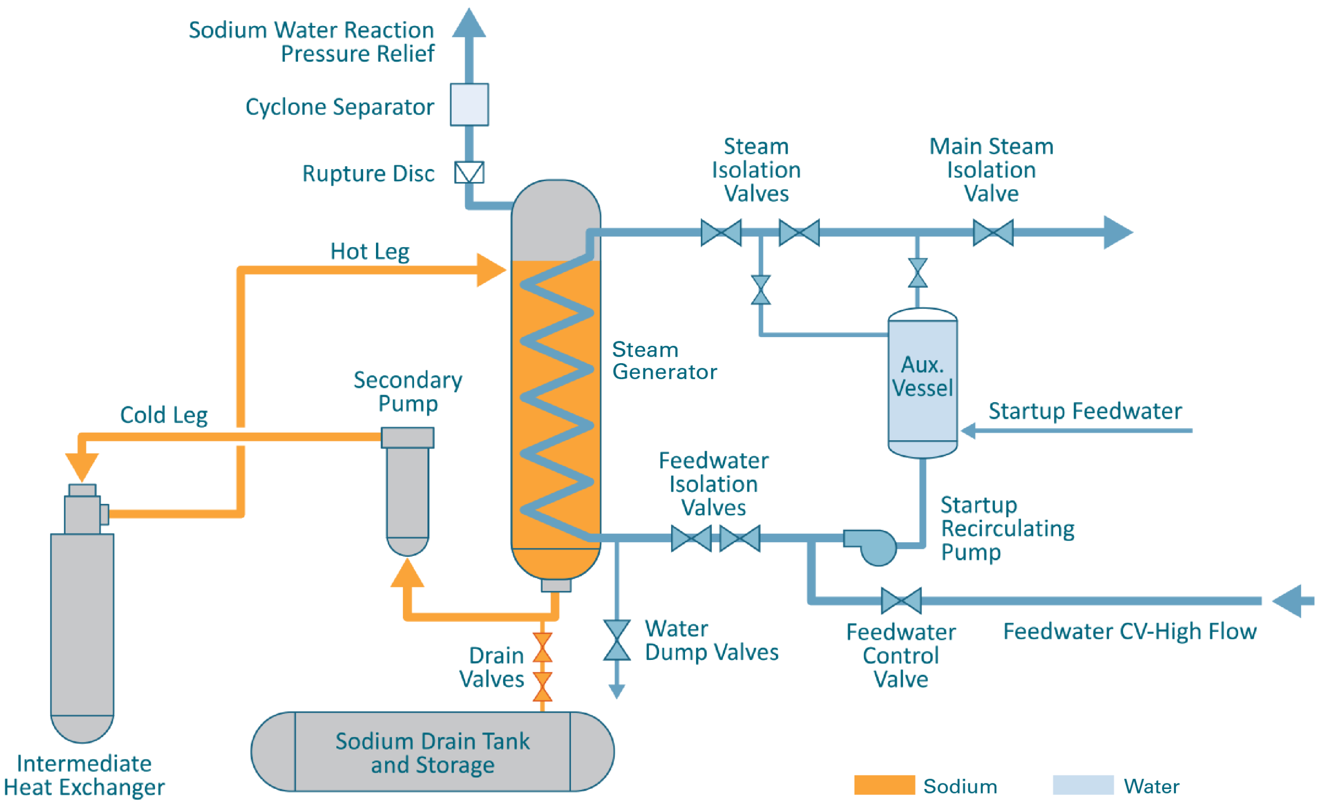


Figure 3-9 Steam Generator and Auxiliaries

3.5 Emergency Core Cooling

The ARC-100 is equipped with two independent emergency core cooling systems that act to remove heat from the reactor core.

3.5.1 Direct Reactor Auxiliary Cooling System

The direct reactor auxiliary cooling system (DRACS) is composed of three independent cooling loops. Each heat removal loop includes a liquid-to-liquid heat exchanger located in the cold pool region of the reactor vessel and a liquid-to-air heat exchanger located in the reactor auxiliary building. The direct reactor auxiliary cooling system uses a sodium-potassium alloy as the heat transfer fluid. During normal operation, the direct reactor auxiliary cooling system air heat exchangers use fans for forced convection to transfer heat to the atmosphere and, if required, rely on natural air circulation during accident scenarios. The cold air inlet vents and hot air outlet vents for each direct reactor auxiliary cooling system loop are physically separated in the reactor auxiliary building. A simplified diagram is shown in Figure 3-10.

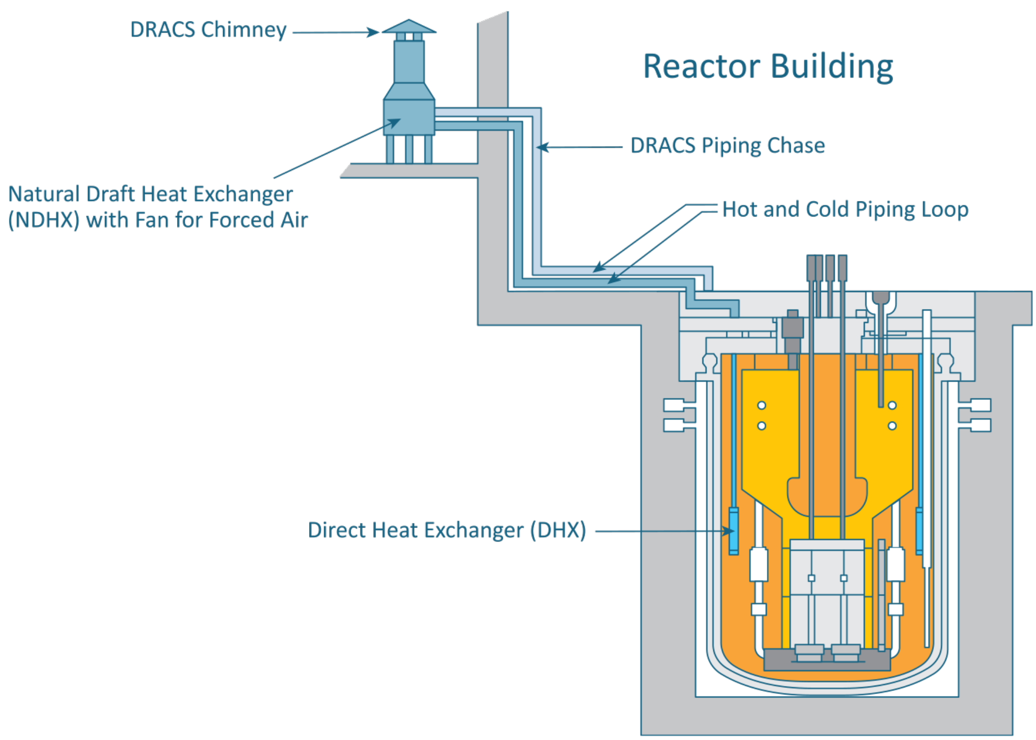


Figure 3-10 Direct Reactor Auxiliary Cooling System (DRACS) schematic

3.5.2 Reactor Vessel Auxiliary Cooling System

The reactor vessel auxiliary cooling system is composed of a collector cylinder below ground, an inlet plenum that connects to four vertical ducts to draw cold air into the collector cylinder, and an outlet plenum that connects to four vertical ducts to discharge hot air to the environment. The collector cylinder is the annular space formed by the below ground, cylindrical concrete containment wall, the guard vessel, and the portion of the reactor support skirt that provides the ceiling of the cylinder. Figure 3-11 shows a schematic of the reactor vessel auxiliary cooling system.

The reactor vessel auxiliary cooling system operates continuously to maintain the reactor vessel and guard vessel shells within structural temperature limits.

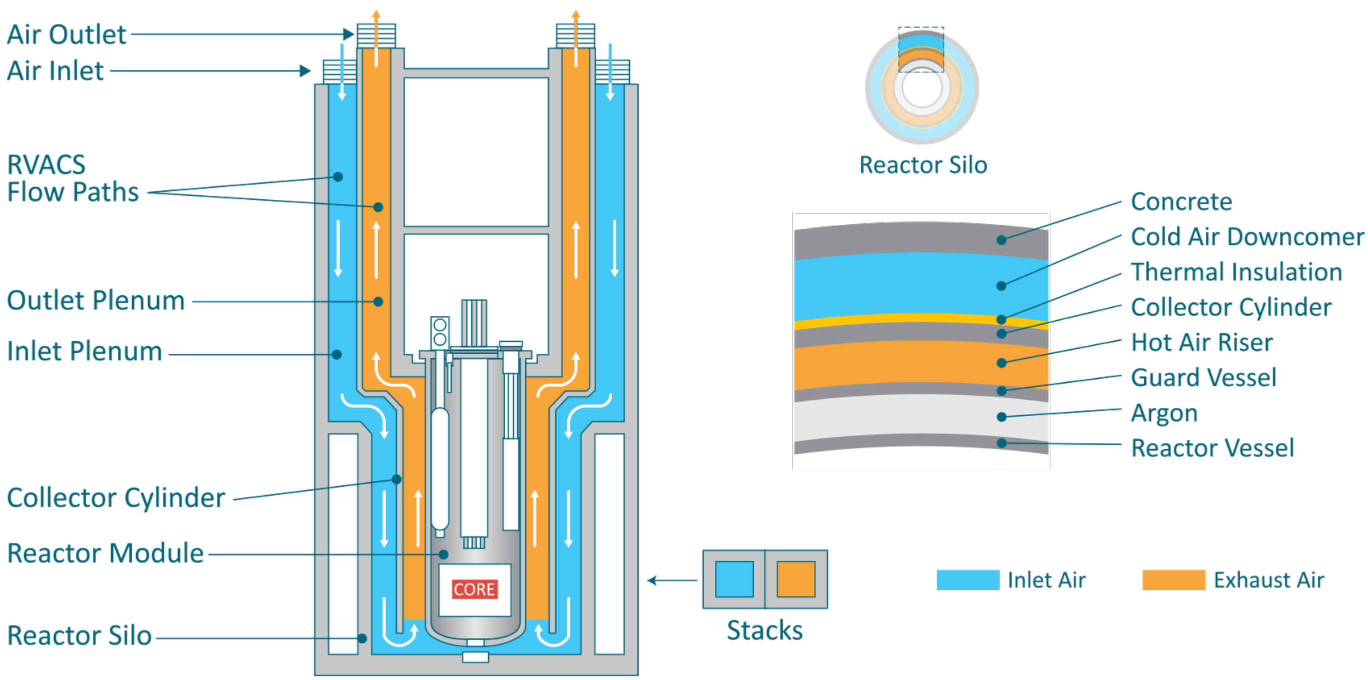


Figure 3-11 Reactor Vessel Auxiliary Cooling System (RVACS) schematic

3.6 Containment System

The containment system provides a continuous envelope around the reactor vessel to ensure that any release of radioactive materials to the external environment during normal operation and accident conditions remain below regulatory limits. It includes a cylindrical concrete structure with the reactor vessel located below ground level and an operating deck above the reactor vessel top plate, as shown in Figure 3-12. The structure includes containment doors, isolation valves in process lines, and dampers in the ventilation ducts that penetrate the containment envelope.

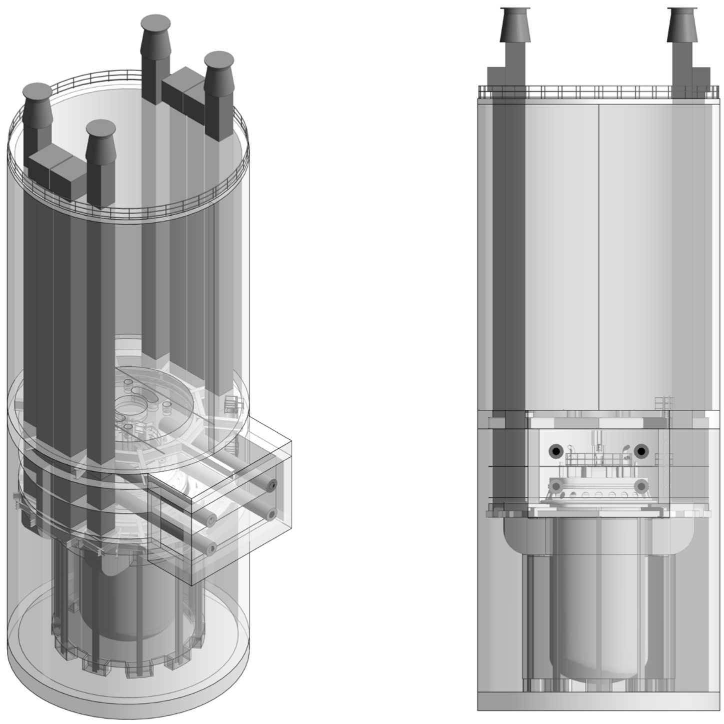


Figure 3-12 ARC-100 Containment Structure

3.7 Fuel Handling and Storage System

The fuel handling and storage system manages fuel from the arrival of new fuel on site to the storage of spent fuel. As refueling of the core only occurs once every 20 years, some of the fuel handling equipment only needs to be available during a refueling campaign. The fuel handling and storage system is divided into new fuel transfer and storage, refueling, and spent fuel transfer and storage.

3.7.1 New Fuel Handling and Storage

New fuel assemblies arrive on the site in their certified fissile material transport containers and are temporarily stored in a dedicated storage location on site until fueling operations begin.

3.7.2 Spent Fuel Handling and Storage

The ARC-100 includes spent fuel storage locations in the reactor vessel with sufficient capacity to hold an entire core load of fuel assemblies.

After 20 years of operation, the irradiated spent fuel assemblies are transferred from the reactor core to the in-vessel fuel storage rack locations using the in-vessel transfer machine. The spent fuel assemblies will then reside in the storage rack locations to allow for thermal decay. A 3-D schematic of in-vessel spent fuel storage is shown in Figure 3-13.

Having decayed sufficiently, the spent fuel assemblies are then moved from their storage rack locations in the reactor vessel and extracted with the use of the ex-vessel transfer machine. The assemblies are then transferred into dry storage modules.

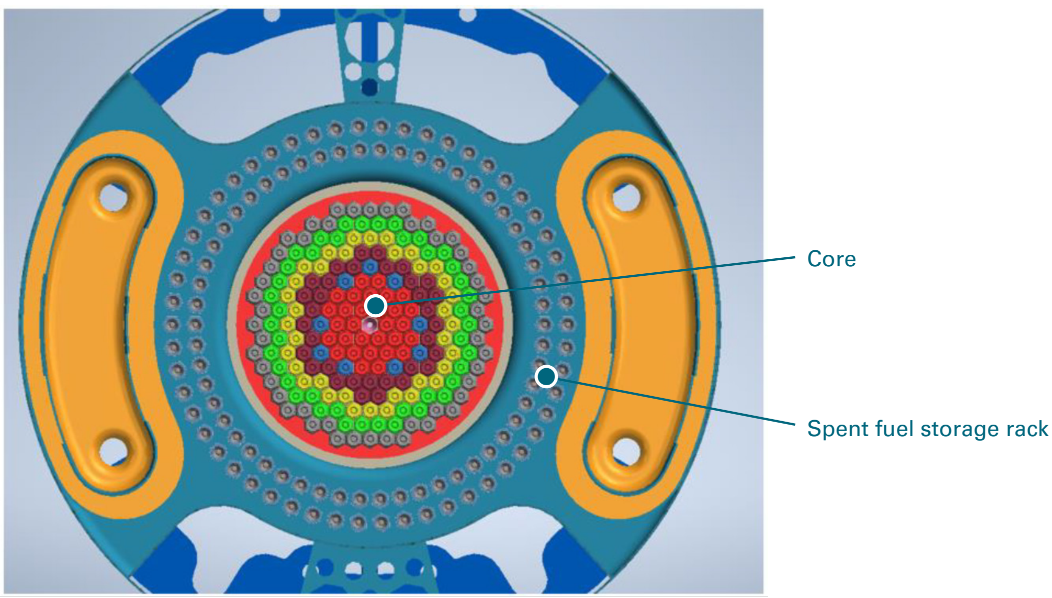


Figure 3-13 Top View of Fuel Storage Schematic

3.7.3 Refueling

To refuel the core, new fuel assemblies are retrieved from their dedicated on-site storage location and transferred from the new fuel transport containers to the reactor with the use of the ex-vessel transfer machine. The new fuel assemblies are then placed into their specified position in the core via the in-vessel transfer machine.

4 ELECTRICAL POWER PRODUCTION SYSTEMS

The turbine generator system and the condensate and feedwater systems are based on commercially available designs for a 100 Megawatts electric plant. They have been selected to meet the specified design requirements to ensure that reliability objectives for the ARC-100 are met.

4.1 Turbine Design

The main turbine is a single casing, non-reheat, combined intermediate and low- pressure turbine, as illustrated in Figure 4-1. A side exhaust has been chosen to minimize Turbine Island cost.

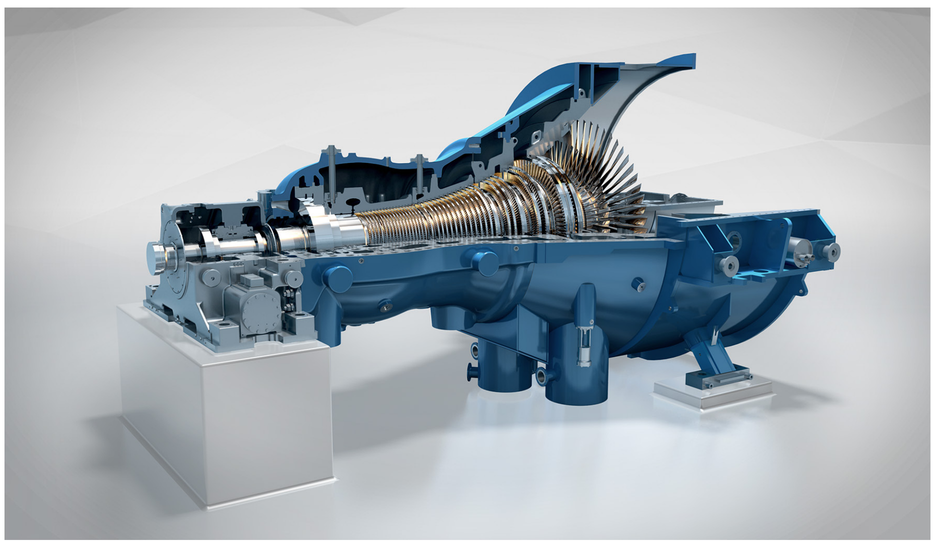


Figure 4-1 Main Turbine [8]
[Source: GE]

4.2 Condensing System

The condensate and feedwater system collects water from the main turbine and auxiliaries, after available thermal energy in the water has been extracted. The system then conditions the water and returns it to the steam generator at the design temperature and pressure.

4.3 Generator Design

The generator is a highly optimised, high efficiency, air-cooled unit. An example is shown in Figure 4-2. The stator is equipped with multi-chamber cooling to allow for efficient heat transfer, and the direct axial rotor winding cooling system allows all the generator sections to achieve a high level of temperature uniformity.

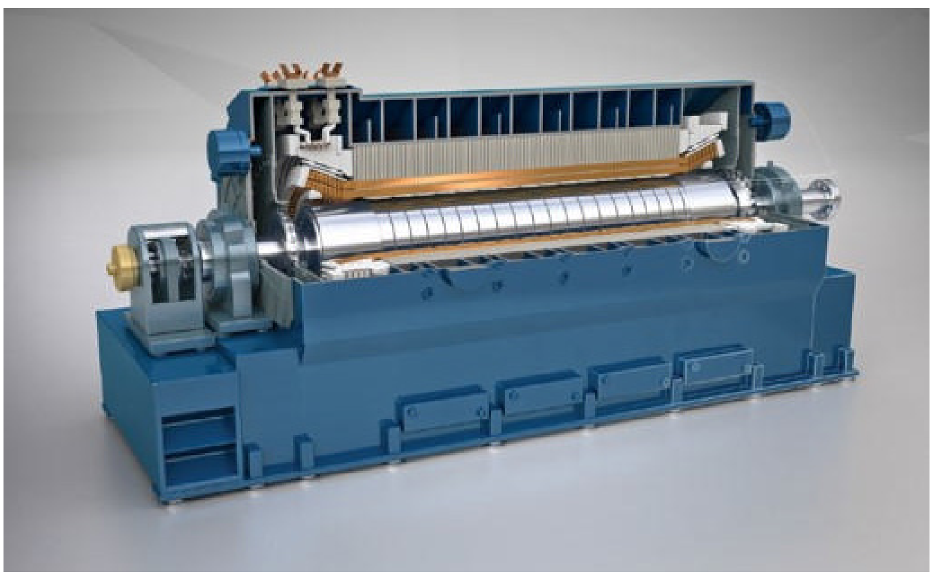
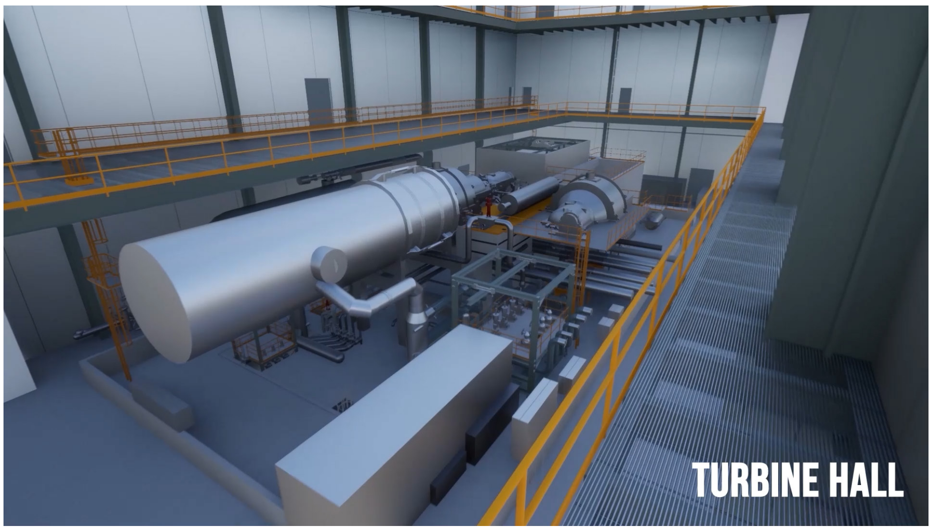


Figure 4-2 Air Cooled Generator [8]
[Source: GE]

4.4 Auxiliary Systems

The turbine auxiliary steam system transports the steam produced by the steam generator to its point of use and extracts its available thermal energy via auxiliary equipment. Included within this system are the systems needed to support the operation of the main turbine generator in the turbine generator hall, shown in Figure 4-3. The turbine generator auxiliary systems provide supportive services to the turbine generator via cooling, sealing, lubricating, and control functions to sustain the operation and ensure maximum efficiency of the turbine generator.



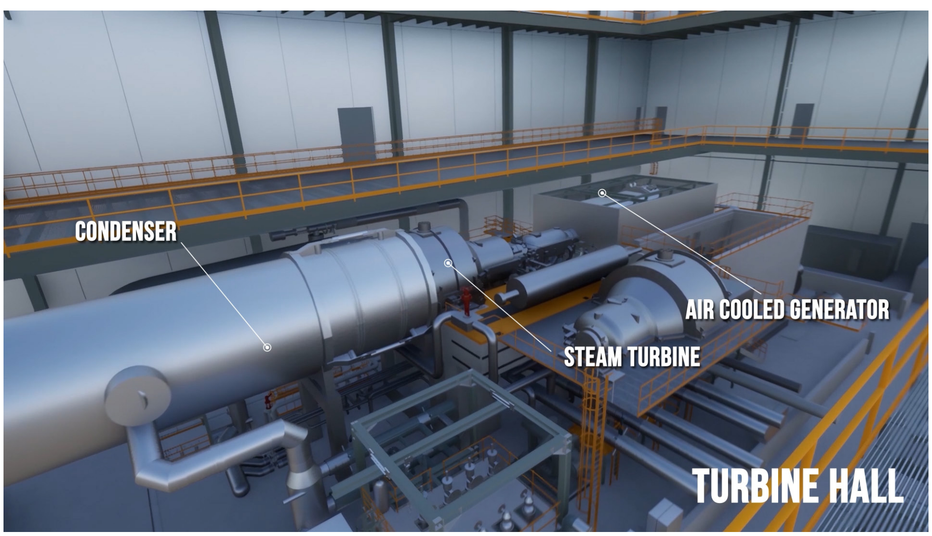


Figure 4-3 Turbine Generator Hall

5 ELECTRICAL, INSTRUMENTATION, AND CONTROL SYSTEMS

The ARC-100 electrical system provides an integrated power supply and transmission system consisting of connections to the off-site grid, the turbine generator, the associated main output system, on-site standby generators, battery power supplies, uninterruptible power supplies, and distribution equipment.

The ARC-100 distributed control and information system provides an integrated control and monitoring system for the power plant.

5.1 Electrical Systems

The ARC-100 electrical system is comprised of four classes of power:

- Class I from several diverse back up battery banks
- Class II delivered from back up battery banks
- Class III from standby generators
- Class IV from the main generator and/ or the local transmission system

The ARC-100 electrical system includes standard electrical connection panels to facilitate the use of mobile power supplies in the event they are needed during a beyond design basis accident.

5.2 Instrumentation and Control (I&C) Systems

The ARC-100 distributed control and information system is comprised of sub-systems to support the following plant functions:

- Control and monitoring of plant systems for electricity generation
- Monitoring and actuation of safety systems using seismically qualified instrumentation and control hardware to mitigate the consequences of design basis accidents
- Monitoring and control of plant conditions using seismically qualified equipment to maintain the plant in a safe state after design basis accidents and accidents beyond the design basis or design extension conditions

5.2.1 General

The ARC-100 distributed control and information system combines modern distributed control, display, and network communication technologies with analog logic. This design provides the following benefits:

- Reduced number of instrumentation and control components, leading to improved reliability and reduced maintenance and construction costs.
- Increased automation to free the operations staff from tedious or stressful tasks, which reduces the potential frequency of operator error.
- Improved information and data communications systems that facilitate awareness of the operational state, providing better detection and diagnosis of faults, and reducing plant outages.
- Use of analog logic for redundant and diverse backup for reactor trip parameters to further improve reliability.
- Low voltage uninterruptible power is used for the shutdown systems fail-safe when the alternating current electrical power is lost.
- As sub-systems of the distributed control and information system, the reactor protection system and the diverse protection system use three-division control and monitoring system design, each with separate and independent power supply electrical systems.

5.2.2 Control Centers

The ARC-100 plant includes the following control centers, where operations staff monitor, control, and operate the plant in both operating states and accident conditions. These control centers are maintained with environmental conditions suitable for habitability.

Main Control Room
The main control room, as illustrated in Figure 5-1, includes consoles for the human-machine interfaces required to operate the plant safely and efficiently under normal operation and to maintain the plant in a safe state under accident conditions.

Secondary Control Room
The secondary control room provides a separate, redundant facility where operations staff can shut down the reactor and maintain it in a safe state in the event the main control room is disabled during accident conditions. Control instrumentation, a safety parameter display system, and communications systems are provided to support accident management.

Technical Support Center
The technical support center is used as an assembly area for plant management and technical support to the operations staff located in the main control room or secondary control room during accident conditions.

On-Site Emergency Support Facility
The on-site emergency support facility provides an environmentally controlled center where operations support personnel assemble to coordinate on-site and off-site emergency response during accident conditions. A safety parameter display system and communications systems are provided to support accident management by the operations support personnel.

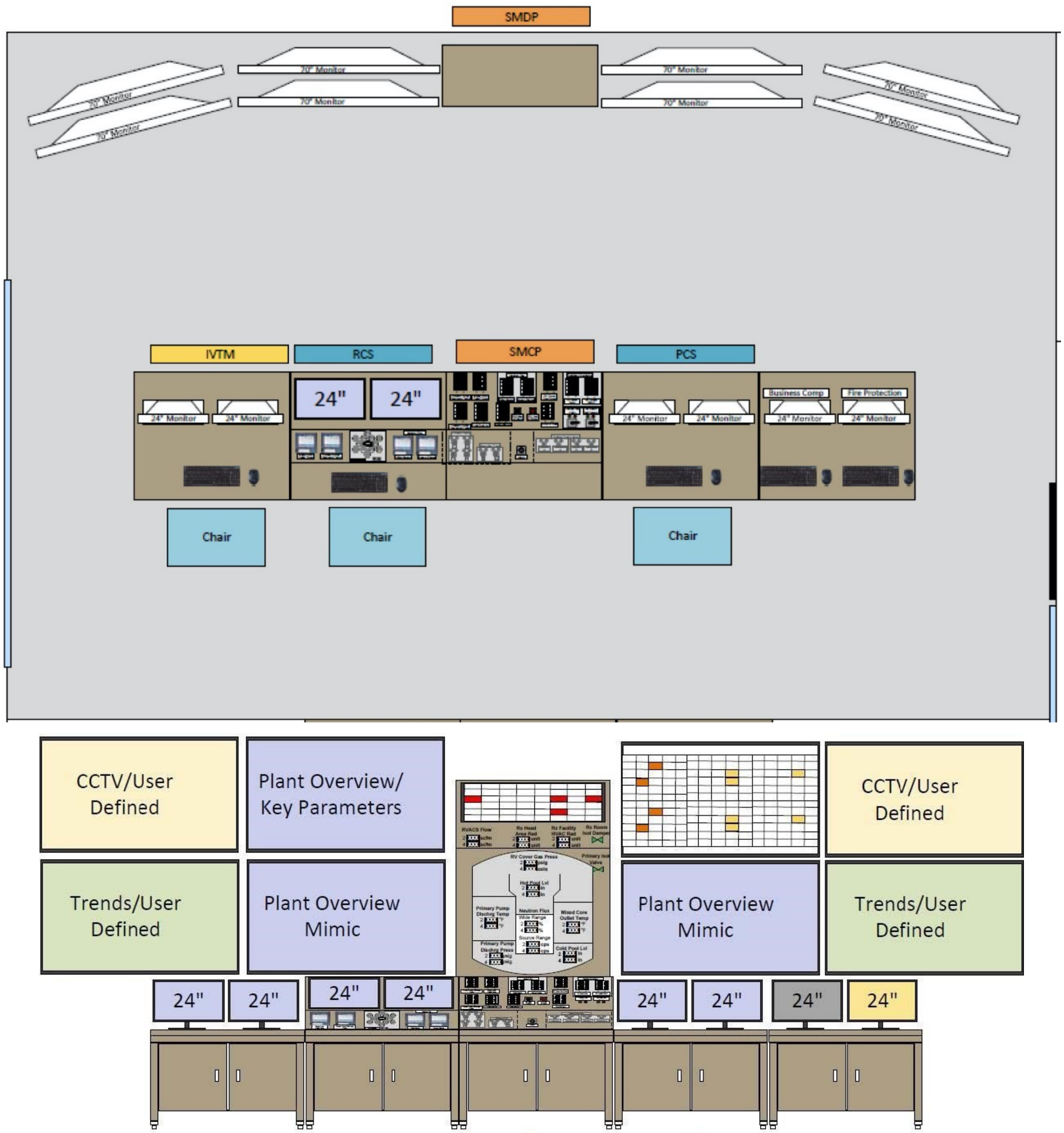


Figure 5-1 Main Control Room

6 SAFETY AND SAFETY SUPPORT SYSTEMS

6.1 Safety Systems

The ARC-100 reactor has the following safety systems, which are designed to shut down the reactor, remove decay heat, and limit radioactivity release following the unlikely failure of normally operating process systems:

Shutdown System No. 1
Shutdown system No. 1 consists of the reactor protection system that monitors specific neutronic and process parameters to ensure safe operating envelope limits are not exceeded, and the shut-off rod system that drops poised shut-off rods into the core under gravity when the reactor protection system actuates its trip signals. A diverse protection system provides a backup means for actuating trip signals. A schematic of a shut-off rod is shown in Figure 6-1.

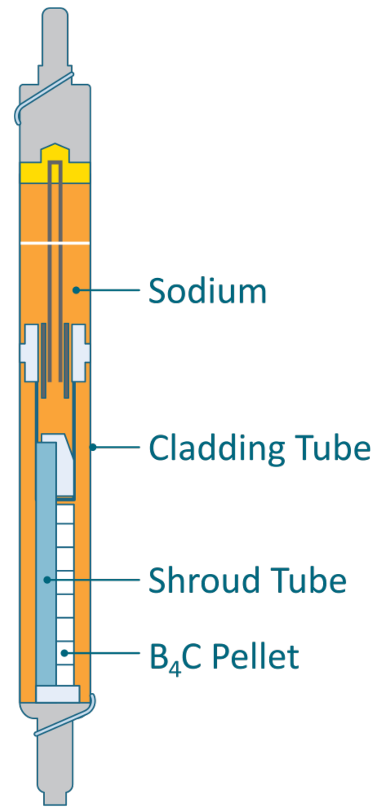


Figure 6-1 Shut-off Rod Schematic

Shutdown System No. 2
Shutdown system No. 2 consists of the inherent reactivity feedback system that monitors specific neutronic and process parameters to ensure safe operating envelope limits are not exceeded. When the diverse protection system actuates its trip signals to isolate the steam generator, the intermediate heat transport system stops removing heat from the core and the reactor temperature increases. The temperature increase causes the inherent negative reactivity system to induce negative reactivity in the core. The increasing negative reactivity feedback, due to loss of neutrons, causes the core to become subcritical.

Complementary Means of Shutdown
The complementary means of shutdown is a complementary design feature that consists of separate instrumentation and control equipment to de-energize the electromagnetic solenoids and drop the primary control rods into the core under gravity during accidents beyond the design basis or design extension conditions. Both the control and shut-off rod drive mechanisms have a motor run-in feature to ensure that the control rods are inserted into the core when the electromagnetic solenoids are de-energized.

Direct Reactor Auxiliary Cooling System
The direct reactor auxiliary cooling system is described in Section 3.5.1. The direct reactor auxiliary cooling system transfers decay heat from the sodium pool using direct reactor auxiliary cooling system heat exchangers located in the cold pool of the reactor vessel using natural circulation of sodium–potassium alloy to the atmosphere through air draft heat exchangers. During normal operation, fans flow air through the air draft heat exchangers. During accident conditions, when power to the fans is lost, the dampers fall completely open to maximize passive decay heat removal to the atmosphere. The direct reactor auxiliary cooling system has a redundant design to achieve the safety function of the removal of decay heat from the fuel, including in a design basis accident scenario where one division is continuously out of service.

Reactor Vessel Auxiliary Cooling System
The reactor vessel auxiliary cooling system is described in Section 3.5.2. The reactor vessel auxiliary cooling system provides continuous removal of the reactor's decay heat through the reactor vessel and guard vessel walls by radiation and convection to naturally circulating air in the annulus between the outside of the guard vessel and the cylindrical concrete wall. The reactor vessel auxiliary cooling system is designed to maintain the safety function of the removal of decay heat from the Reactor Vessel including in a design basis scenario where only one half of the inlet/outlet stacks are available.

Containment System
The containment system provides a continuous envelope around the reactor vessel to ensure that the release of any radioactive materials to the external environment during normal operation and accident conditions remains well below regulatory limits. The system consists of a cylindrical concrete structure equipped with containment doors and isolation valves and dampers on all process lines and ventilation ducts that penetrate containment.

6.2 Safety Support Systems

The passive, fail-safe designs of the ARC-100 safety systems means that only a limited demand for uninterruptible power is required for the functioning of the safety systems during design basis accidents, accidents beyond the design basis, or design extension conditions:

- The shut-off rod system requires uninterruptible power for its motor run-in function, as a back-up feature, to ensure that the shut-off rods fully insert into the core on demand.
- The primary control rod system requires uninterruptible power for its motor run-in function to ensure that the primary control rods fully insert into the core on demand during accidents beyond the design basis or design extension conditions.

Uninterruptible electrical power is also provided for continuous monitoring of safety critical parameters to guide operator actions.

6.3 Complementary Design Features

The ARC-100 reactor includes the following systems and complementary design features to prevent the occurrence of severe accidents and to mitigate severe core damage in the unlikely event of such an occurrence:

- Large thermal capacity of sodium in the reactor vessel
- Passive decay heat removal from the core and containment system by direct reactor auxiliary cooling system and reactor vessel auxiliary cooling system
- Robust containment structure that provides a low leakage barrier
- Inherent negative reactivity to maintain the core subcritical when the sodium temperature is elevated
- Complementary means of shutdown to shut down the reactor as an independent back-up to the two shutdown systems
- A guard vessel that provides a secondary coolant boundary by enclosing the reactor vessel to ensure the fuel remains cooled by sodium in the highly unlikely event the reactor vessel leaks

6.4 Emergency Planning Measures

The ARC-100 design includes an on-site emergency support center and plans for on-site and off-site emergency response.

On-Site Emergency Support Center
The On-Site Emergency Support Center is located to facilitate assembly of the on-site operations support personnel. It is equipped with a safety parameter display system, a dedicated on-site and off-site communication system, and a voice communication system to coordinate with operating staff in the main control room, secondary control room, and technical support center.

Technical Support Center
The Technical Support Center is used as an assembly area for plant management and technical support for operating staff located in the main control room or secondary control room during emergency conditions. It is equipped with a safety parameter display system, radiation monitoring for the plant and immediate surroundings, meteorological monitoring, communication systems for on-site and off-site communication, storage space for emergency plans, procedures, protective clothing, drawings, and cabinets housing equipment for first aid.

7 SAFETY, SECURITY, AND SAFEGUARDS

The ARC-100 has an integrated implementation of safety design provisions, nuclear security measures and nuclear material accounting processes to satisfy International Atomic Energy Agency safeguards requirements.

7.1 Nuclear Safety Requirements

From a nuclear security point of view, the following nuclear safety requirements ensure safe shutdown of the reactor, removal of decay heat, and monitoring of plant safety until the security event is stabilized and mitigation can be conducted:

- The containment structure is sufficiently robust against design basis threats such that uncontrolled release of fission products outside of containment is prevented.
- In the event of a radioactive release, the dose to members of the public is below regulatory limits.
- Systems required for shutdown, decay heat removal, and monitoring of the reactor continue to be available.
- Operation of systems "important to safety" is possible in the event of attack or sabotage causing adverse conditions such as fire, smoke, and structural damage, until mitigation can be conducted.
- The plant layout integrates access requirements for operations and maintenance with radiation protection requirements for workers and security requirements to provide a multi-level defense against both external and internal threats.

7.2 Nuclear Security

The ARC-100 security strategies and objectives use five defense-in-depth levels:

1. Deterrence
2. Detection
3. Delay
4. On-site security response
5. Off-site security response

A combination of multiple layers of physical systems and equipment, plant layout, and procedures (including the arrangements for on-site security forces and off-site response forces) must be overcome or circumvented before physical protection is compromised. This defense-in-depth approach for nuclear security parallels the defense-in-depth approach for nuclear safety.

The physical security requirements for the ARC-100 are:

- Fuel, systems, and equipment that are "important to safety", and the sabotage of which could lead to unacceptable radiological consequences, are located within vital areas.
- Access and the number of access points to the protected area(s) and the vital area(s) are kept to a minimum. All emergency exits are fitted with intrusion detection sensors. Other points of potential access are secured and alarmed.
- The design and construction of vital areas provide penetration delay. Vital areas are secured, and alarms set when unattended.
- A series of independent physical barriers are provided which are consistent with the defense-in-depth principle.
- The protected area is provided with a robust physical barrier including intrusion detection. Clear areas are provided on both sides of the perimeter of the protected area with illumination sufficient for assessment.
- A continuously staffed and hardened security monitoring room is provided.
- All intrusion detection sensors shall annunciate in the security monitoring room.
- Dedicated and tamper indicating transmission systems and power supplies (from uninterruptible emergency power) are provided between the security monitoring room and the intrusion detection systems.
- Dedicated and diverse transmission systems for two-way communication between the security monitoring room and the response force are provided.

7.2.1 Design Basis Threat and Beyond Design Basis Threat

The ARC-100 is designed to resist a set of threats that are categorized as design basis threats and beyond design basis threats. Threats identified as design basis threats have credible attributes and characteristics of potential insider or external adversaries who might attempt sabotage against a physical protection system are designed and evaluated. Beyond design basis threats are less frequent and more severe than design basis threats, their consequences are assessed in order to establish means of mitigation to the extent practicable.

Three types of threats are considered during the life of the plant:

1. **National design basis threats**
   The national design basis threat definition is based on a threat risk assessment by the national regulator and is reviewed periodically, per applicable regulations, and can change during the life of the plant. Local design changes may be made to the ARC-100 standard plant design to satisfy these requirements for a specific site.

2. **Project-specific threats**
   These threats are considered in the design of the ARC-100 standard plant and can be categorized as design basis threats and beyond design basis threats.

3. **Site-specific threats**
   Local design changes may be made to the ARC-100 standard plant design to satisfy threats specific to the site location and plant characteristics.

7.3 Safeguards

The ARC-100 design facilitates application of safeguards measures required by the International Atomic Energy Agency.

7.3.1 Features Contributing to Proliferation Resistance

The ARC-100 design includes intrinsic and extrinsic features that facilitate International Atomic Energy Agency surveillance, item accountancy verification, and minimize the attractiveness of this technology as a target for proliferation, such as:

- The fuel is U-10%Zr binary metallic fuel with an average uranium enrichment of 13.1wt%, which is defined by the International Atomic Energy Agency as a nuclear material that cannot be used for the manufacture of nuclear explosive devices without transmutation or further enrichment.
- The limited access to the reactor vessel results in a core that is only accessible during outages.
- The extraction of fuel assemblies requires the use of lifting equipment and shielded casks for transport.
- The 20 year refueling cycle results in a limited amount of spent fuel assemblies.
- In-vessel storage of spent fuel assemblies is protected by access to the reactor vessel and can be monitored, accounted for, and verified.
- Access to the reactor vessel and spent fuel in-vessel and dry storage is easily monitored by installing International Atomic Energy Agency containment/surveillance seals.
- Use of the fuel handling equipment is very infrequent and easily monitored by installing International Atomic Energy Agency containment/surveillance seals.
- Existing International Atomic Energy Agency surveillance equipment is suitable for monitoring spent fuel in dry storage.

8 RADIOACTIVE AND HAZARDOUS WASTE MANAGEMENT

8.1 Waste Management

The ARC-100 plant uses, as much as practicable, well-proven commercially available waste management systems and equipment. The radioactive waste system provides the equipment for collecting, processing, monitoring, storing, and disposing of liquid and solid radioactive wastes within areas of the radioactive maintenance and waste building. The radioactive waste system consists of the liquid radioactive waste system, a solid radioactive waste system, and a separate gaseous radioactive waste system to processes airborne radionuclides.

8.1.1 Spent Fuel Dry Storage

Interim spent fuel dry storage will use a proven dry storage system, currently used for dry storage of light-water reactor fuel assemblies. Although space has been allocated on the ARC-100 plant site for the spent fuel dry storage facility, the first interim spent fuel dry storage module will not be required until several years after the first refueling of the reactor core.

8.1.2 Solid Radioactive Waste

The solid radioactive waste system collects, characterizes, compacts, packages, and prepares compactible radioactive solid wastes and packages non-compactible radioactive solids for disposal using conventional waste management equipment.

8.1.3 Liquid Radioactive Waste

The liquid radioactive waste system uses evaporation to process liquid waste. The resulting solid waste is packaged and the vapors from the evaporation process are filtered for the limited number of processes that generate liquid radioactive waste, i.e., contaminated fluids from washing primary sodium coolant from components.

8.1.4 Gaseous Radioactive Waste

The gaseous radioactive waste system receives, analyzes, and filters airborne radionuclides that could exist in areas of the plant. This is done locally where there is a potential for radioactive gas being present.

For example, argon cover gas within the reactor vessel is supplied using a closed system that includes a subsystem for collecting, monitoring, treating, and filtering radioactive gases, vapours, and airborne particulates released from the sodium pool. Controlled discharges to the atmosphere take place when maintenance of the argon cover gas system requires purging.

8.1.5 Hazardous Non-Radioactive Waste

Commercial equipment is used to handle and package hazardous non-radioactive wastes for disposal at off-site disposal facilities. Hazardous non-radioactive wastes include solid sodium and sodium–potassium alloy compounds.

9 RADIATION PROTECTION

Implementation of the radiation protection philosophy for ARC-100 design ensures that radiation exposure to workers and members of the public during normal plant operation are as low as reasonably achievable, considering social and economic factors. Design targets based on experience in operating nuclear power plants are established to support application of the as low as reasonably achievable principle. This approach ensures that the design satisfies regulatory dose limits with large margins.

Features that minimize radiation exposure include:

- Radiation zones are defined to divide the plant into areas related to their expected occupancy, radiation, and contamination levels in all operational states and accident conditions.
- Shielding is provided to prevent or reduce radiation exposures.
- As far as is reasonably practicable, materials used in the manufacture of structures, systems and components are selected to minimize activation of the material.
- Systems are designed to collect, monitor, treat or filter radioactive substances, prior to controlled releases to the environment.

10 DECOMMISSIONING

Decommissioning experience of sodium-cooled fast reactors around the world guides the design of the ARC-100. Design improvements to address the lessons learned from previous decommissioning activities are considered as part of the design process.

The ARC-100 decommissioning strategy includes physical and radiological characterization, facility and site decontamination, and materials management.

The objective is to maintain a decommissioning planning process during the lifecycle of the plant that will be periodically updated during the operation phase to ensure that the resources are available when decommissioning takes place after the end of the operating life of the plant.