IRIS

INTERNATIONAL REACTOR INNOVATIVE AND SECURE

IRIS Plant Overview

October 17, 2002

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1 INTRODUCTION

The IRIS (International Reactor Innovative and Secure) is a pressurized light water cooled, medium power (1000 MWt) reactor. The IRIS development program was originally sponsored by the US Department of Energy (DOE) as part of the NERI (Nuclear Energy Research Initiative) program and has now been selected as an International Near Term Deployment (INTD) reactor, within the Generation IV International Forum activities. The IRIS concept also addresses the top-requirements defined by the US DOE for next generation reactors, i.e. enhanced reliability and safety, and improved economics. The IRIS is an innovative design, but it does not require new technology development, since it relies on the proven light water reactor technology.

The IRIS is being developed by an international consortium led by Westinghouse Electric Co.. The IRIS consortium includes a number of US and international companies, universities and national laboratories and organizations. Table 1 lists the IRIS consortium members.

IRIS fuel assemblies have standard Westinghouse features but can operate over a three to four-year long fuel cycle. The IRIS design features an integral reactor vessel that contains all the reactor coolant system components, including the pressurizer, steam generators, and reactor coolant pumps. This integral reactor vessel configuration allows the use of a small, high design pressure, spherical steel containment resulting in a high level of safety and economic attractiveness. The IRIS reactor development has employed a "safety by design" approach that has eliminated or reduced the consequences of most accident sequences. In order to take advantage of the extended IRIS fuel cycle and to improve the overall plant availability, an optimized maintenance approach for all major components is being developed, which will also extend the interval between maintenance shutdowns to as long as 48 months.

The IRIS design still builds on the proven technology provided by 40 years of operating PWR experience, and on the established use of passive safety features pioneered by Westinghouse in the NRC certified AP600 plant design. Like the AP600 and the AP1000 designs, the IRIS safety features, once actuated, rely on natural driving forces such as gravity and natural circulation flow for their continued function. These safety systems do not use active components (such as pumps, fans or diesel generators) and are designed to function without safety-grade support systems (such as AC power, component cooling water, service water, or HVAC). Because of the safety by design approach, the number and complexity of the safety systems and required operator actions are further minimized in IRIS. The net result is a design with significantly reduced complexity and improved operability, and extensive plant simplifications to enhance construction.

The IRIS is being designed to comply with all applicable US NRC criteria. Safety analyses and a Probabilistic Risk Analysis (PRA) are in progress and a testing program is being developed. The preliminary PRA results show a very low core damage frequency that meets the goals established for advanced reactor designs and a low frequency of release due to an innovative reactor and containment cooling strategy. The simplified safety systems reduce surveillance requirements by enabling significantly simplified technical specifications. Built-in testing capability is provided for critical components.

The IRIS plant layout will ensure adequate access for inspection and maintenance. Laydown space for staging of equipment and personnel, equipment removal paths, and space to accommodate remotely operated service equipment and mobile units are part of the plant design. Access platforms and lifting devices are provided at key locations, as are service provisions such

Table 1. IRIS Consortium

Industry		
Westinghouse	USA	Overall coordination, core design, licensing
BNFL	UK	Fuel and fuel cycle
Ansaldo Energia	Italy	Steam generators design
Ansaldo Camozzi	Italy	Steam generators fabrication
ENSA	Spain	Vessel and internals
Washington Group EMD	USA	Pumps, CRDMs
NUCLEP	Brazil	Containment, pressurizer
Bechtel	USA	BOP, AE
OKBM	Russia	Testing
Laboratories		
ORNL	USA	I&C, PRA, core analyses, shielding
ININ	Mexico	Neutronics, PRA support
CNEN	Brazil	Transient and safety analyses, pressurizer design
Universities		
Polytechnic of Milan	Italy	Safety analyses, shielding, thermal hydraulics, steam generators design, advanced control system
Tokyo Inst. of Technology	Japan	Advanced cores, PRA
University of Zagreb	Croatia	Neutronics, safety analyses
University of Pisa	Italy	Containment analyses
Power Producers		
TVA	USA	Maintenance, utility feedback
Eletronuclear (pending)	Brazil	Developing country utility feedback
Associated US Universities (NERI programs)		
MIT	USA	Advanced cores, maintenance
U. California Berkeley	USA	Neutronics, advanced cores
U. of Tennessee	USA	Modularization, I&C
Ohio State	USA	In-core power monitor, advanced diagnostics
Iowa State (Ames Lab)	USA	On-line monitoring
U. of Michigan (& Sandia Lab)	USA	Monitoring and control

as electrical power, demineralized water, breathing and service air, ventilation and lighting. The IRIS design also incorporates radiation exposure reduction principles to keep worker dose as low as reasonably achievable (ALARA). Exposure length, distance, shielding and source reductions are fundamental criteria that are incorporated into the design. Various features have been incorporated in the design to minimize construction time and total cost by eliminating components and reducing bulk quantities and building volumes. Some of these features include the following:

- A small, 25 meter diameter, containment building that eliminates in-containment refueling activities. These activities are conducted in the fuel handling area where adequate space for equipment laydown and work space are provided.

- The flat, common basemat design selected for the nuclear island effectively minimizes construction cost and schedule.
- Utilization of the integrated protection system, the advanced control room, distributed logic cabinets, multiplexing, and fiber optics, significantly reduces the quantity of cables, cable trays, and conduits.
- A key feature of the IRIS plant configuration is the stacked arrangement of the Class IE battery rooms, the dc switchgear rooms, the integrated protection system rooms, and the main control room. This stacked arrangement eliminates the need for the upper and lower cable spreading rooms that are required in the current generation of PWR plants.
- Application of the passive safeguards systems replaces and/or eliminates many of the conventional mechanical safeguards systems that are typically located in the Seismic Category I buildings in the current generation of PWR plants.

The IRIS is designed with environmental consideration as a priority. The safety of the public, the power plant workers, and the impact to the environment have all been addressed as specific design goals, as follows:

- Operational releases have been minimized by design features.
- Aggressive goals for worker radiation exposure have been set.
- Total radwaste volumes have been minimized.
- Other hazardous waste (non-radioactive) has been minimized.

The IRIS design is taking advantage of previous design efforts that were made in the ALWR program that developed the AP600 plant design and others. This includes use of the Utility Requirements Document (URD) for ALWRs developed by Electric Power Research Institute (EPRI) with a broad participation of numerous countries. The URD takes into account the wealth of information related to nuclear power plant safety and operations that has been generated worldwide with commercial nuclear power. The purpose of the URD is to delineate utility desires for their next generation of nuclear plants, and to this end, it consists of a comprehensive set of design requirements for future plants. In this way, the IRIS has a well-defined design basis that is confirmed through thorough engineering analyses and testing and is in conformance with the URD. Some of the high-level design characteristics and goals of the plant are:

- ♦ Net electrical power of approximately 335 MWe; and a thermal power of 1000 MWt.
- ♦ Core design is robust with an extended fuel cycle length and at least a 15% operating margin on core power parameters.
- ♦ Short lead time (four years from owner's commitment to commercial operation) and construction schedule (two years).
- ♦ No plant prototype is needed since the power generating system components used are well based in current technology and will be extensively tested in their IRIS applications.
- ♦ Major safety systems are passive; they require no operator action or off-site assistance for 1 week after an accident, and additional core and containment cooling is provided for a protracted time without ac power.
- ♦ Predicted core damage and release frequency are very low, and are significantly less than the published NRC required 1E-05/yr and 1E-06/yr requirements.
- ♦ Standard design will be applicable to all anticipated US sites.
- ♦ Occupational radiation exposure expected to be well below 0.7 man-Sv/yr (70 man-rem/yr).
- ♦ The core design is capable of operating on a 4-year fuel cycle;
- ♦ Refueling and maintenance outages will be less frequent than the current outage schedules.
- ♦ Plant design life of 60 years without replacement of the reactor vessel.

♦ Overall plant availability greater than 95%, including forced and planned outages; the goal for unplanned reactor trips is less than one per year.

2 DESCRIPTION OF THE NUCLEAR SYSTEMS

2.1 Primary circuit and its main characteristics

IRIS is a pressurized water reactor featuring an integral primary circuit layout instead of the typical PWR loop layout. All the main primary system components (core, pressurizer, reactor coolant pumps and steam generators) are located inside the reactor pressure vessel, as shown in Figure 1.

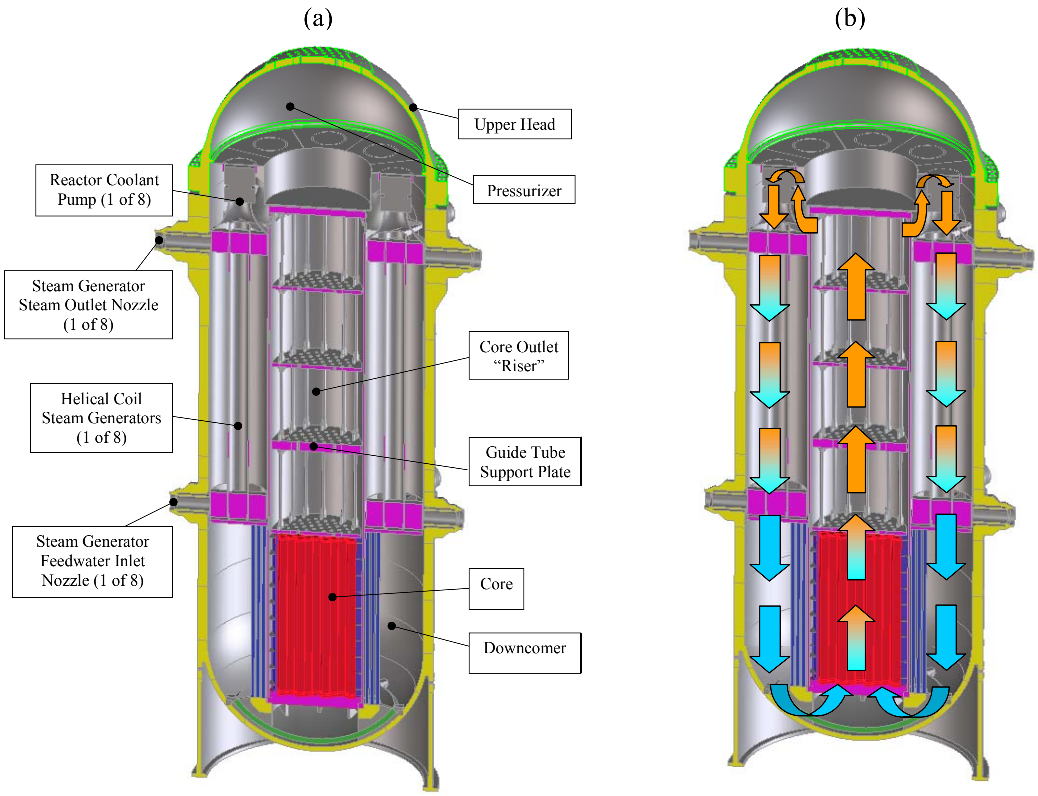

Figure 1: IRIS integral layout: (a) main components; (b) main flow path

The primary coolant flow path is illustrated in Fig. 1(b). Water flows upwards through the core and upward through the riser region (defined by the extended core barrel). At the top of the riser, the coolant is directed into the upper annular plenum where the suction of the reactor coolant pumps is located. Eight pumps are employed, and the flow of each pump is directed downward through its associated helical coil steam generator module. The flow path continues down through the annular downcomer region outside the core to the lower plenum and then back to the core completing the primary coolant flow path.

The integral primary circuit layout eliminates primary piping outside the pressure vessel and large primary vessel penetrations, thus eliminating the possibility of large break loss of coolant events. It is amenable to an overall reduction of other piping, thus reducing the probability of occurrence for small break loss of coolant events.

The integral reactor coolant system pressure boundary provides a barrier against the release of radioactivity generated within the reactor and is designed to provide a high degree of integrity throughout operation of the plant.

2.2 Reactor core and fuel design

The IRIS core and fuel characteristics are similar to those of a conventional Westinghouse PWR design. However, several features have been modified to enhance performance as compared to conventional plants, while retaining existing technology. An IRIS fuel assembly consists of 264 fuel rods in a 17x17 square array. The central position is reserved for in-core instrumentation, while the remaining 24 positions have guide thimbles. The IRIS fuel assembly design is similar to the Westinghouse 17x17 XL Robust Fuel Assembly design and AP1000 fuel assembly design. Low-power density is achieved by employing a core configuration consisting of 89 fuel assemblies (shown in Fig. 2) with a 14-foot (4,267 mm) active fuel height, and a nominal thermal power of 1,000 MWt. This results in reduction of the average linear power density by about 25 percent as compared to AP600. The improved thermal margin provides increased operational flexibility, while enabling longer fuel cycles and increased overall plant capacity factors.

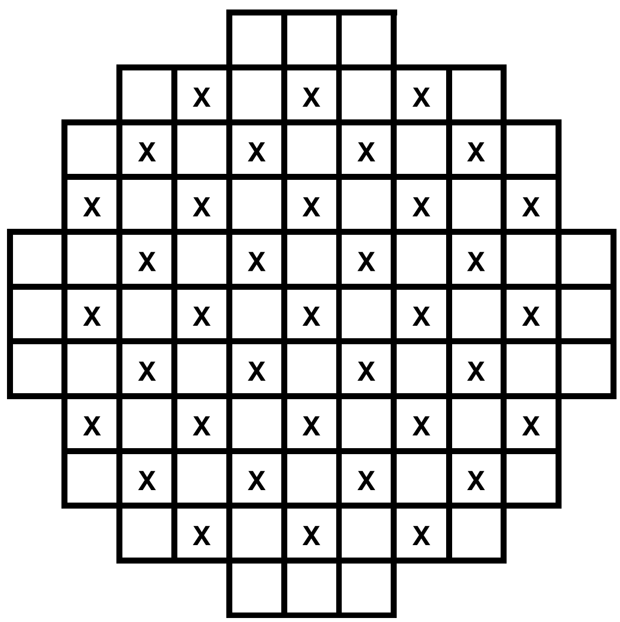

Fig. 2 IRIS core configuration and a typical RCCA pattern

The IRIS fuel employs a lattice design with enhanced moderation that results in increased discharge burnup or reduced enrichment requirements. Another feature that contributes to lowering fuel cycle cost and extending reactor life is the use of a stainless steel radial neutron reflector (Fig. 3). This reflector reduces neutron leakage thereby improving core neutron utilization. As a result, fuel utilization is improved as well, thus enabling extended fuel cycle and increased discharge burnup. The radial reflector has the added benefit of reducing the fast neutron fluence on the core barrel and reactor vessel and the dose outside the vessel.

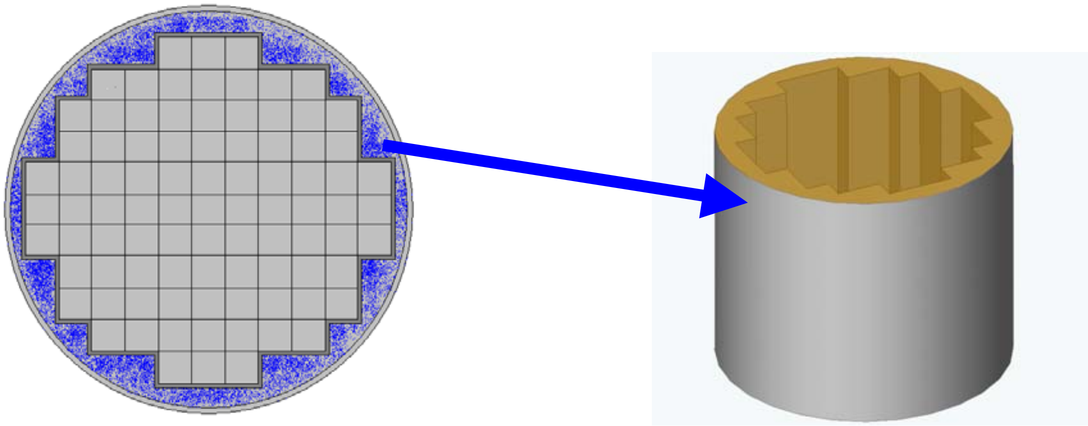

Fig. 3 IRIS radial neutron reflector assembly(conceptual; design details not shown)

Reactivity control is achieved in a traditional manner by a combined use of soluble boron, integral absorbers, and control rods. However, soluble boron concentration is reduced as compared to conventional PWR cycles, to improve core response in transients (more negative reactivity coefficients) and reduce the amount of waste to be processed. Another core design feature (common with the AP600 and AP1000 design) is the use of reduced-worth control rods ("gray" rods) to achieve daily load follow while minimizing the required change in the soluble boron concentration. With the exception of the neutron absorber materials used, the design of the gray rod assembly is identical to that of a normal control rod assembly.

Several reloading strategies are available depending on the utility requirements and priorities. When the cycle length is the primary objective, straight-burn core design utilizing enrichment close to 5% can provide a four-year cycle lifetime with a burnup of ~40,000 MWd/tU. The use of erbium Integral Burnable Absorber ensures adequate reactivity control while maintaining a negative temperature coefficient of reactivity. A more traditional multi-batch reloading enables achieving average batch discharge burnup of ~50,000 MWd/tU (for a two-batch reload scheme), or up to ~60,000 MWd/tU (for three-batch reload scheme). The two-batch reload is compatible with the currently US NRC licensed maximum allowed burnup (62,000 MWd/tU lead rod average) and is therefore the current reference core design. The three-batch reloading scheme may be implemented in the future to improve fuel economy, when fuel with higher allowed discharge burnup (e.g., 62/75,000 MWd/tU batch and lead rod average) becomes licensed.

Moreover, the IRIS core was designed to facilitate future upgrade and transition to a long eight-year cycle (possibly with a short maintenance shut-down at mid-cycle) by using 8-10% enriched UO_2 fuel or MOX fuel with 10-12% Pu.

2.3 Fuel handling and transfer systems

The IRIS reactor vessel (RV) is contained in a spherical, steel containment vessel (CV) that is 25 meters (82') in diameter (see Figure 4). The containment vessel has a bolted and flanged closure head at the top that provides access to the RV upper head flange and bolting. Refueling of the reactor is accomplished by removing the containment vessel closure head and installing a sealing collar between the CV and RV flanges (a permanent seal is provided between the CV and refueling cavity), and removing the RV head. The refueling cavity above the containment and RV is then flooded, and the RV internals are removed and stored in the refueling cavity. Fuel assemblies are vertically lifted from the RV directly into a fuel handling and storage area, using a refueling machine located directly above the CV. Thus, no refueling equipment is required inside containment and the single refueling machine, located in the fuel handling area is used for all fuel movement activities. In addition, this arrangement eliminates the in-containment polar crane, since all heavy reactor components are accessed through the containment closure head and are handled by the fuel handling over-head bridge crane.

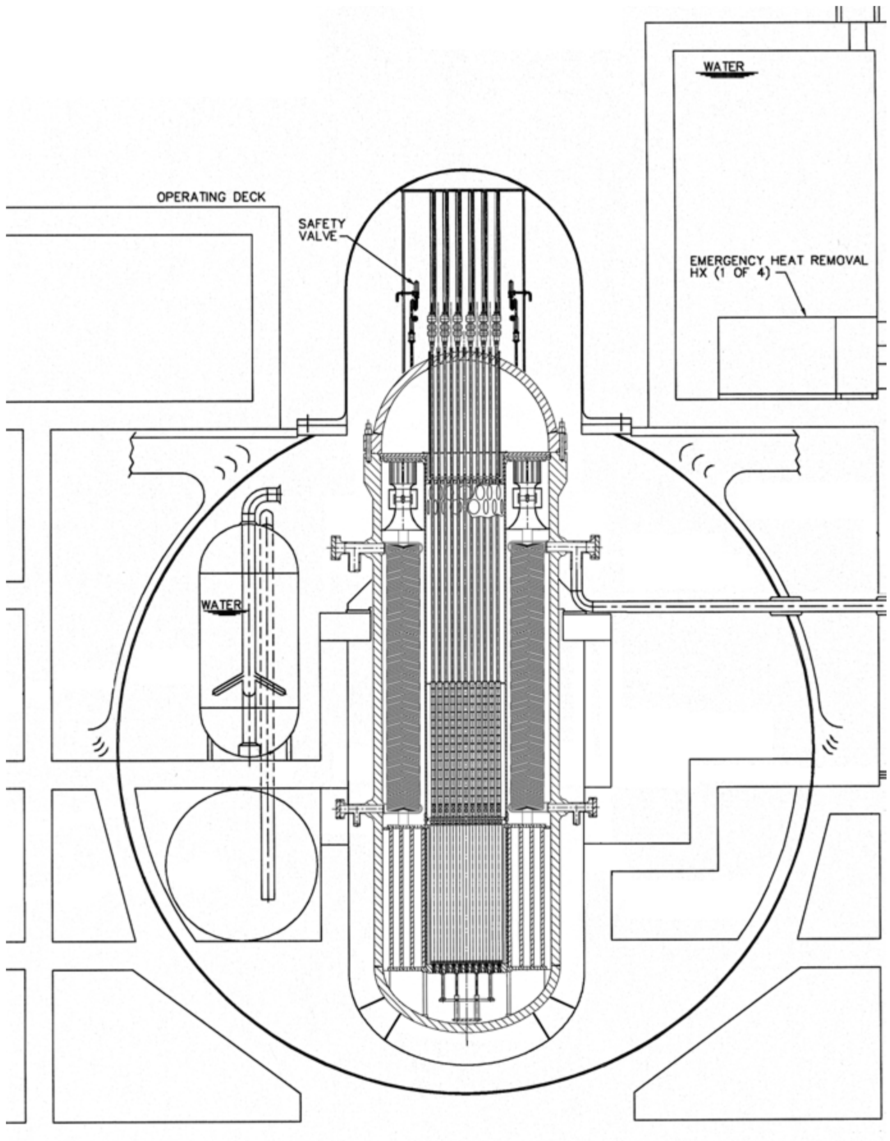

Figure 4 IRIS Spherical Steel Containment

<u>New fuel storage</u>
New fuel will be stored, as in latest Westinghouse reactor designs, in a high density rack which includes integral neutron absorbing material to maintain the required degree of subcriticality. The new fuel rack is located in the fuel handling portion of the reactor auxiliary building and it is designed to store fuel of the maximum design basis enrichment of 4.95% enriched uranium. The rack in the new fuel pit consists of an array of cells interconnected to each other at several elevations and to supporting grid structures at the top and bottom elevations. The new fuel rack includes storage locations for 89 fuel assemblies. Minimum separation between adjacent fuel

assemblies is sufficient to maintain a subcritical array even in the event the building is flooded with unborated water or fire extinguishing aerosols or during any design basis event.

Spent fuel storage

Spent fuel will be stored, as in latest Westinghouse reactor designs, in high density racks which include integral neutron absorbing material to maintain the required degree of subcriticality. The racks are designed to store fuel of the maximum design basis enrichment. Each rack in the spent fuel pool consists of an array of cells interconnected to each other at several elevations and to supporting grid structures at the top and bottom elevations. The spent fuel storage racks include storage locations for 356 fuel assemblies, which provides a minimum storage capability corresponding to 18 years of plant operation, with room for a full core off-load. Of course, additional spent fuel storage capacity can be provided in this new design, based on the requirements and capability to ship spent fuel to a repository. The spent fuel rack module will additionally contain integral storage locations for five defective fuel storage containers, and the rack is designed such that a fuel assembly can not be inserted into a location other than a location designed to receive an assembly.

2.4 Primary components

Reactor pressure vessel

The IRIS reactor vessel (RV) is an integral configuration which houses not only the nuclear fuel and control rods, but also all the major reactor coolant system (RCS) components (see Figure 1). This includes: eight small, spool type, reactor coolant pumps (RCPs); eight modular, helical coil, once through steam generators (SGs); a steel reflector which surrounds the core in the RV downcomer to improve neutron economy and reduce neutron fluence on the RV; and a pressurizer located in the RV upper head. This simplified integral arrangement eliminates the individual component pressure vessels and large connecting loop piping between them, resulting in a compact, more economic configuration and in the elimination of the large loss-of-coolant accident as a design basis event. Because the IRIS integral vessel contains all the RCS components, it is larger than a traditional RV, and has an ID of 6.2 meters and an overall height of 21.3 meters including the closure head.

The major in-vessel components are described below:

- **Reactor core** (described in section 2.2)

- **Reactor coolant pumps -** An advanced reactor coolant pump (RCP) has been adopted as the reference for the IRIS reactor. IRIS will feature a "spool type" pump that has been used in marine and chemical plant applications requiring high flow rates and low developed head. The motor and pump consist of two concentric cylinders, where the outer ring is the stationary stator and the inner ring is the rotor that carries high specific speed pump impellers. The spool type pump is located entirely within the reactor vessel; only small penetrations for the electrical power cables are required. High temperature motor windings and bearing materials are being developed to eliminate any need for cooling water and the associated piping penetrations through the RV. This design is a significant improvement over the typical canned motor RCPs which have the pump/impeller extending through a large opening in the pressure boundary with the motor extending outside where the motor casing becomes part of the pressure boundary and is typically flanged and seal welded to the mating pressure boundary surface. In addition to the above advantages derived from its integral location, the spool pump geometric configuration provides high inertia/coastdown and high run-out flow capability that will contribute to mitigate the consequences of Loss-Of-Flow

Accidents (LOFAs). Because of their low developed head, spool pumps have never been candidates for nuclear applications. However, the IRIS integral RV configuration and low coolant loop pressure drop can accommodate these pumps and take full advantage of their unique characteristics.

- **Steam generators** – The IRIS SGs are a once-through, helical-coil tube bundle design with the primary fluid outside the tubes. Eight steam generator modules are located in the annular space between the core barrel (outside diameter 2.85 m) and the reactor vessel (inside diameter 6.2 m). Each IRIS SG module consists of a central inner column that supports the tubes, the lower feed water header and the upper steam header, and an outer wrapper. The enveloping outer diameter of the tube bundle is 1.64 m. Each SG has 656 tubes, and the tubes and headers are designed for the full external RCS pressure. The tubes are connected to the vertical sides of the lower feedwater header and the upper steam header. The SG is supported from the RV wall and the headers are bolted to the vessel from the inside of the feed inlet and steam outlet pipes. A double gasket, with a monitor leak-off, provides the pressure boundary between the primary coolant and the secondary side feed water inlet and steam outlet penetrations in the reactor vessel.

  Feed water enters the SG through a nozzle in the reactor vessel wall and enters the lower feed water header. The feedwater enters the SG tubing, and is heated to saturation temperature, boiled, and superheated as it flows upward to the upper steam header. Steam then exits the SG through the nozzle in the reactor vessel wall.

  The helical SG tube bundle is contained within an outer wrapper (flow shroud) that directs the primary water flow from the top of the SG, downward through the bundle (outside the tubes), and out the bottom of the bundle into the reactor vessel downcomer region. Each of the eight reactor coolant pumps is attached directly to the top of its corresponding SG flow shroud, so that its flow is entirely directed through the SG bundle region.

  The helical-coil tube bundle design is capable of accommodating thermal expansion without excessive mechanical stress, and has high resistance to flow-induced vibrations. A prototype of this SG was successfully tested by IRIS team member Ansaldo in an extensive test campaign conducted on a 20 MWt full diameter, part height, test article. The performance characteristics (thermal, vibration, pressure losses) were investigated along with the determination of the operating characteristics domain for stable operation.

- **Pressurizer** - The IRIS pressurizer is integrated into the upper head of the reactor vessel. The pressurizer region is defined by an insulated , inverted top-hat structure that divides the circulating reactor coolant flow path from the saturated pressurizer water. This structure includes a closed cell insulation to minimize the heat transfer between the hotter pressurizer fluid and the subcooled water in the primary water circulating flow path. Heater rods are located in the bottom portion of the inverted top-hat and are positioned outside the CRDM drive lines. The bottom portion of this inverted top-hat contains holes to allow water insurge and outsurge to/from the pressurizer region. These surge holes are located just below the heater rods so that insurge fluid flows up along the heater elements.

  By utilizing the upper head region of the reactor vessel, the IRIS pressurizer provides a very large water and steam volume, as compared to plants with a traditional, separate, pressurizer vessel. The IRIS pressurizer has a total volume of 71.41 m^3, which includes a steam volume of ~49 m^3. This steam volume is about 1.6 times bigger than the AP1000 pressurizer steam space, while IRIS has ~1/3 the core power. This large steam volume to power ratio contributes to the fact that IRIS does not require the use of a pressurizer spray function to prevent the pressurizer safety valves from lifting for any design basis heatup transients.

2.5 Reactor auxiliary systems

Chemical and volume control system

The IRIS chemical and volume control system (CVCS) consists of a high pressure purification loop located inside containment, and the makeup and chemical addition portion of the system which is located outside containment. The inside containment, high design pressure portion of the CVCS includes the regenerative and letdown heat exchangers, demineralizers and filters, a canned circulation pump. and associated valves, piping, and instrumentation. The reactor coolant is demineralized, filtered, and returned to the reactor vessel without leaving the containment. The outside containment portion of the CVCS includes the makeup pumps, tanks, chemical and hydrogen addition equipment, and associated valves, piping, and instrumentation. The chemical and volume control system is designed to perform the following major tasks:

• Purification - maintain reactor coolant purity and activity level within acceptable limits.
• Reactor coolant system inventory control and makeup - maintain the required coolant inventory in the reactor coolant system; maintain the programmed pressurizer water level during normal plant operations.
• Chemical shim and chemical control - maintain the reactor coolant chemistry conditions by controlling the concentration of boron in the coolant for plant startups, normal dilution to compensate for fuel depletion and shutdown boration and provide the means for controlling the reactor coolant system pH by maintaining the proper level of lithium hydroxide.
• Oxygen control - provide the means for maintaining the proper level of dissolved hydrogen in the reactor coolant during power operation and for achieving the proper oxygen level prior to startup after each shutdown.
• Filling and pressure testing of the reactor coolant system - the chemical and volume control system does not perform hydrostatic testing of the reactor coolant system, which is only required prior to initial startup and after major, non-routine maintenance, but provides connections for a temporary hydrostatic test pump.
• Borated makeup to auxiliary equipment - provide makeup borated water to the primary side systems which require borated reactor grade water.
• Pressurizer Auxiliary Spray - provide pressurizer auxiliary spray water for depressurization.

Normal residual heat removal system

The normal residual heat removal system consists of two mechanical trains of equipment, each comprising one pump and one heat exchanger. The two trains of equipment each have a suction line from the reactor vessel and their discharge flow returns cooled water back to the reactor vessel via one of the two direct vessel injection connections. The normal residual heat removal system includes the piping, valves and instrumentation necessary for system operation. The major functions of the system are:

• Shutdown Heat Removal. The normal residual heat removal system removes both residual and sensible heat from the core and the reactor vessel. It reduces the temperature of the reactor coolant system during the second phase of plant cooldown. The first phase of cooldown is accomplished by transferring heat from the reactor coolant system via the steam generators to the main steam system. Following cooldown to 350°F with the steam generators, the normal residual heat removal system reduces the temperature of the reactor coolant system from 350° to 120°F (177 to 49 °C) within 96 hours after shutdown. The normal residual heat removal system then maintains the reactor coolant temperature at or below 120°F during the plant shutdown

operations, until the plant is started up. The normal residual heat removal system also provides the following functions:
• Shutdown Purification. The normal residual heat removal system provides reactor coolant system flow to the chemical and volume control system during refueling operations.
• Low Temperature Overpressure Protection. The normal residual heat removal system includes safety relief valves that provide the low temperature overpressure protection function for the reactor coolant system during refueling, startup, and shutdown operations.
• Long-Term, Post-Accident Containment Inventory Makeup. The normal residual heat removal system provides a flow path for long term post-accident makeup to the reactor/containment when/if required to maintain inventory, under design assumptions of containment leakage.

2.6 Operating characteristics

The plant control scheme will be specifically designed for operation with the once-through steam generators and will be based on the "reactor follows plant load" strategy. A grid fluctuation will be automatically compensated for through turbine control valves in case of a frequency drop, and a decrease in pressure at the turbine will result in an increase in reactor power. IRIS is designed, similar to AP600/AP1000, to withstand the following operational occurrences without the generation of a reactor trip or actuation of the safety related passive engineered safety systems:

- ± 5%/minute ramp load change within 15% and 100% power
- ±10% step load change within 15% and 100% power
- 100% generator load rejection
- 100-50-100% power level daily load follow over 90% of the fuel cycle life
- Grid frequency changes equivalent to 10% peak-to-peak power changes at 2%/minute rate
- 20% power step increase or decrease within 10 minutes
- Loss of a single feedwater pump

The logic and setpoints for all of the IRIS Nuclear Steam Supply System (NSSS) control systems are being developed in order to meet the above operational transients without reaching any of the protection system setpoints.

3 DESCRIPTION OF TURBINE GENERATOR PLANT SYSTEM

3.1 Turbine generator plant

The IRIS turbine design is not yet finalized but will consist of an 1800-rpm machine with a double-flow, high-pressure cylinder and one double-flow, low-pressure cylinder with exhausts to individual condensers. . The turbine generator is intended for base load operation and also has load follow capability. The single direct-driven generator is gas-cooled and rated at 447 MVA at 22 kV, and a power factor of 0.9.
Steam from the eight steam generators is combined into four steam line penetrations through the containment. These four lines extend to the high-pressure turbine through four stop valves and four governing control valves. Crossties are provided upstream of the turbine stop valves to provide pressure equalization with one or more stop valves closed. After expanding through the high-pressure turbine, exhaust steam flows through one external moisture separator reheater vessel. The external moisture separator reduces the moisture content of the high-pressure exhaust steam and the reheater uses a portion of the main steam supply to reheat the steam to superheated conditions. The reheated steam flows through separate reheat stop and intercept valves to the inlets of the low-pressure turbine. Turbine steam extraction connections are provided for seven

stages of feedwater heating in order to maximize the cycle efficiency. The condenser and circulating water systems have been optimized for both performance and ability to perform routine maintenance. The condenser is a twin-shell, multi-pressure unit with one low-pressure turbine exhausting into the top of each shell.
The turbine-generator and associated piping, valves, and controls are located completely within the turbine building. There are no safety-related systems or components located within the turbine building. Other related system components located within the turbine building include the turbine-generator bearing lubrication oil system, a digital electrohydraulic (DEH) control system with supervisory instrumentation, a turbine steam sealing system, over-speed protective devices, turning gear, a generator hydrogen and seal oil system, a generator CO_2 system, an exciter cooler, a rectifier section, an exciter, and a voltage regulator.
The IRIS building design and layout will preclude the possibility of postulated turbine-generator high-energy missiles affecting safety-related structures, systems, or components so that the failure of the turbine-generator equipment does not preclude the safe shutdown of the reactor. The turbine-generator components and instrumentation associated with turbine-generator over-speed protection are accessible under operating conditions, so that the risks of over-speed events is minimized.

3.2 Condensate and feedwater systems

The IRIS condensate and feedwater systems supply the steam generators with clean, heated feedwater in a traditional, closed, steam cycle using regenerative feedwater heating. Full-flow cleanup of the condensate is provided to minimize deposits in the IRIS once-through steam generators. The feedwater cycle consists of seven stages of feedwater heating with two parallel string, low-pressure feedwater heaters located in the condenser neck with the next two single-string, low-pressure heaters, deaerator, and the high-pressure heaters located within the turbine building. The condenser hotwell and deaerator storage capacity provides sufficient storage to prevent minor, short-duration mismatches in flow from affecting plant operation. This margin, coupled with three 50 percent condensate and main feedwater pumps, provides operational flexibility and the ability for an operator to control feedwater and condensate transients.

3.3 Auxiliary systems

Radioactive waste management
As AP600/AP1000, the IRIS reactor plant is designed to deal with liquid, gaseous and solid radioactive waste. The liquid waste systems include the radioactive waste drain system and the liquid radwaste system that collects and treats all water drained from the reactor. Treated liquid is stored and monitored before being discharged in a controlled manner.
The gaseous radwaste system is a once-through, ambient-temperature, charcoal delay system. The system consists of a drain pot, a gas cooler, a moisture separator, an activated charcoal-filled guard bed, and two activated charcoal-filled delay beds. Also included in the system are an oxygen analyzer subsystem and a gas sampling subsystem. The primary source of radioactive gas is the liquid radwaste system degasifier. This degasifier extracts both hydrogen and fission gases from the chemical and volume control system letdown flow. The radioactive fission gases entering the system are carried by hydrogen and nitrogen gas.
The solid waste management system is designed to collect and accumulate spent ion exchange resins, deep bed filtration media, spent filter cartridges, dry active wastes, and mixed wastes generated as a result of normal plant operation, including anticipated operational occurrences. The system is located in the auxiliary and radwaste buildings. Processing and packaging of wastes takes place in the radwaste building where the waste is stored until it is shipped offsite to a disposal facility.

4 INSTRUMENTATION AND CONTROL SYSTEMS

The I&C system design will be integrated and will be based on the latest digital technology. Anticipated benefits from this technology will build on the already advanced I&C provided in the AP600/1000 designs.

4.1 Design concept, including control room

The IRIS instrumentation and control architecture will be arranged in a hierarchical manner to provide a simplified, structured design that is horizontally and vertically integrated. As in the most advanced designs, information is pulled up from a data highway/monitor bus to control centers and data displays that facilitate the interaction between the plant operators and the I&C. The portions of the I&C that perform the protective, control, and data monitoring functions operate directly from the plant sensors. These include the protection and safety monitoring system, the plant control system, and the in-core instrumentation system. The plant control system (PLS) has the function of establishing and maintaining the plant operating conditions within prescribed limits. The control system improves plant safety by minimizing the number of situations for which some protective response is initiated and relieves the operator from routine tasks. The protection and safety monitoring system is the safety grade system that provides reactor trip and safeguards component actuation signals. It is designed to be highly redundant and to prevent common mode failures. However, in the low-probability case where a common mode failure could occur, a diverse actuation system (DAS) provides an alternative means of initiating the reactor trip and emergency safety features. The hardware and software used to implement the DAS are different from the hardware and software used to implement the protection and safety monitoring system. The DAS is included to meet the anticipated transient without (reactor) scram (ATWS) rule and to reduce the probability of a severe accident resulting from the unlikely coincidence of a transient and common mode failure of the protection and safety monitoring.

<u>Control Room</u>
The IRIS operation and control will be provided from an advanced main control room that incorporates the latest man-machine interface features and advanced display and control technologies. In addition IRIS will include a separate remote shutdown workstation, a waste processing control room, and a technical support center. The main control room and the remote shutdown workstation are the signal interfaces with the plant components. These interfaces are via the plant protection and safety monitoring system processor and logic circuits, which interface with the reactor trip and engineered safety features plant components; the plant control system processor and logic circuits, which interface with the non-safety plant components; and the plant monitor bus, which provides plant parameters, plant component status, and alarms.

4.2 Reactor protection system and other safety systems

The IRIS design includes instrumentation and controls to automatically sense transient or accident situation, trip the reactor, and initiate the engineered safety features with no need for operator actions. These actions are designed to prevent damage to the core, as well as mitigate the consequences of the postulated events and provide containment integrity. The protection and safety monitoring system (PMS) provides the safety-related functions necessary during normal operation, to shut down the plant, and to maintain the plant in a safe shutdown condition. The protection and safety monitoring system controls the safety-related components in the plant that are operated from the main control room or remote shutdown workstation.

5 ELECTRICAL SYSTEMS

The IRIS on-site power system design concept will be similar to the on-site power systems developed for the other Westinghouse advanced passive (AP) plants. The on-site power system is designed to provide reliable electric power to the plant safety and non-safety equipment for normal plant operation, startup, and normal shut down, and for accident mitigation and emergency shutdown. The on-site power systems include the main AC power system and the DC power system. The main AC power is a non-Class IE system. The DC power system consists of two independent systems, one Class IE and one non-Class IE.

5.1 Operational power supply systems

The main AC power system is a non-Class IE system that does not perform any safety function. The standby power supply is included in the on-site standby power system. The power to the main AC power system normally comes from the station main generator through unit auxiliary transformers. The plant is designed to sustain a load rejection from 100 percent power with the turbine generator continuing stable operation while supplying the plant house loads. The on-site standby AC power system is powered by the two on-site standby diesel generators and supplies power to selected loads in the event of loss of the normal AC power supplies.
The plant DC power system comprises two independent Class IE and non-Class IE DC power systems. Each system consists of ungrounded stationary batteries, DC distribution equipment, and uninterruptible power supplies.

6 SAFETY CONCEPT

6.1 Safety requirements and design philosophy

IRIS has been primarily focused on featuring a design with innovative safety characteristics. The IRIS design provides for multiple levels of defense for accident mitigation (defense-in-depth), resulting in extremely low core damage probabilities while minimizing the occurrences of containment flooding, pressurization, and heat-up situations.

The first line of defense in the defense in depth approach is to eliminate initiators that could convincibly lead to core damage. In IRIS, this concept is implemented through the “safety by design” approach, which can be simply described as “design the plant in such a way to eliminate the accidents from occurring, rather than coping with their consequences”. If it is not possible to eliminate the accidents altogether, then the design should be such to inherently reduce their consequences and/or decrease their probability of occurring. The key difference from previous practice is that the integral reactor design is intrinsically conducive to eliminating accidents, to a degree impossible in conventional loop-type reactors. The elimination of the large LOCAs, since no large primary penetrations of the reactor vessel or large loop piping exist, is only the most easily visible of the safety potential characteristics of integral reactors. Many others are possible, but they must be carefully exploited through an appropriate design that is kept focused on selecting design characteristics that are most amenable to eliminate accident initiating events. IRIS has strived to achieve that and some of the main results are summarized in Table 2, which illustrates the implications of the safety by design approach, and in Table 3, that describes the effect of safety by design on some typical design basis events for LWRs. A substantial effort has been exerted and is still underway to perform safety analyses and quantitatively substantiate the behavior summarized in Tables 2 and 3.

Table 2 Implications of Safety By Design Approach

IRIS Design Characteristic	Safety Implication	Accidents Affected
Integral Layout	No large primary piping	- LOCAs
Large, Tall Vessel	Increased water inventory Increased natural circulation Can accommodate internal CRDMs	- LOCAs - Decrease in heat removal - Various events - RCCA ejection, eliminate head penetrations
Heat Removal from inside the vessel	Depressurizes primary system by condensation and not by loss of mass Effective heat removal by SG/EHRS	- LOCAs - LOCAs - All events for which effective cooldown is required - ATWS
Reduced size, higher design pressure containment	Reduced driving force through primary opening	- LOCAs
Multiple coolant Pumps	Decreased importance of single pump failure	- Locked rotor, shaft seizure/break
High design pressure steam generator system	No SG safety valves Primary system cannot over-pressure secondary system Feed/Steam System Piping designed for full RCS pressure reduces piping failure probability	- Steam generator tube rupture - Steam line break - Feed line break
Once Through steam generator	Limited water inventory	- Steam line break - {Feed line break}
Integral Pressurizer	Large pressurizer volume/reactor power	- Overheating events, including feed line break. - ATWS

Table 3 IRIS response to PWR Class IV Events

Design Basis Condition IV Events		Effect of IRIS Safety-by-Design
1	Large Break LOCA	- Eliminated by design (no large piping)
2	Steam Generator Tube Rupture	- Reduced consequences, simplified mitigation
3	Steam System Piping Failure	- Reduced probability, reduced (limited containment effect, limited cooldown) or eliminated (no potential for return to critical power) consequences
4	Feedwater System Pipe Break	- Reduced probability, reduced consequences (no high pressure relief from reactor coolant system)
5	Reactor Coolant Pump Shaft Break	- Reduced consequences
6	Reactor Coolant Pump Shaft Seizure	
7	Spectrum of RCCA ejection accidents	- [Eliminated by design, requires development of internal CRDM]
8	Design Basis Fuel Handling Accidents	- No impact

The IRIS defense-in-depth capability next includes multiple levels of defense for a very wide range of plant events, similar to AP600/AP1000. Defense-in-depth is built into the IRIS design, where the design goal is to always maintain the core covered with water and avoid fuel damage, with a multitude of individual plant features capable of providing some degree of defense of plant safety. After the safety by design, five additional aspects of the IRIS design contribute to defense-in-depth:

<u>Stable Operation</u>. In normal operation, the most fundamental level of defense-in-depth ensures that the plant can be operated stably and reliably. This is achieved by the selection of materials, by quality assurance during design and construction, by well-trained operators, and by an advanced control system and plant design that provide substantial margins for plant operation before approaching safety limits.

<u>Physical Plant Boundaries</u>. One of the most recognizable aspects of defense-in-depth is the protection of public safety through the physical plant boundaries. Releases of radiation are directly prevented by the fuel cladding, the reactor pressure boundary, and the containment pressure boundary. For the fuel cladding boundary, the reactor protection system is designed to actuate a reactor trip whenever necessary to prevent exceeding the fuel design limits. The core design, together with defense-in-depth process and decay heat removal systems, provides this capability under expected conditions of normal operation, with appropriate margin for uncertainties and anticipated transient situations. The reactor coolant pressure boundary is designed with complete overpressure protection and appropriate materials to provide and maintain the boundary during all modes of plant operation. The containment vessel, in conjunction with the defense-in-depth heat removal systems, is designed so that: its design pressure is not exceeded following postulated design basis accidents; a large margin to the design

basis pressure is maintained during postulated design basis accidents to minimize leakage probability; and, containment failure does not occur even under severe accident conditions.

Passive Safety-Related Systems. The next level of defense in design strategy after the safety by design includes the IRIS safety-related passive systems and equipment. The safety-related passive systems are sufficient to automatically establish and maintain core cooling and containment integrity for the plant following design basis events, assuming that the most limiting single failure occurs. These systems maintain core cooling and containment integrity after an event, without operator action and onsite and offsite ac power sources, for an indefinite amount of time. The safety-related passive systems use only natural forces, such as gravity and natural circulation for their continued operation. No pumps, fans, diesels, chillers, or other rotating machinery are used. A few simple valves align the passive safety systems when they are automatically actuated by the safety-related protection and safety monitoring system (PMS). The PMS provides the safety-related functions of reactor trip, engineered safeguards features actuation, and post-accident monitoring. The IRIS design basis for the PMS is to provide an automatic response to any postulated accident, without requiring any operator action for extended periods of time (more than 3 days).

Non-safety Systems. The next design level of defense-in-depth is the availability of certain non-safety systems for reducing the potential for events leading to core damage. For more probable events, these defense-in-depth, non-safety systems automatically actuate to provide a first level of defense to reduce the likelihood of unnecessary actuation and operation of the safety-related systems. These non-safety-related systems establish and maintain safe shutdown conditions for the plant following design basis events, provided that at least one of the nonsafety-related ac power sources is available.
Also, to minimize core damage probability, diverse, non-safety systems are provided to back up the main functions of the passive safety related systems. These systems are being defined on the basis of PRA considerations so to minimize the core damage and the radioactivity release probabilities. This diversity exists, for example, in the residual heat removal function. The emergency heat removal system (EHRS) is the passive safety-related feature for removing decay heat during a transient. In case of multiple failures in the EHRS, defense-in-depth is provided by a simple, non-safety, passive containment cooling system and by the gravity driven injection from the pressure suppression system tanks and automatic depressurization (passive feed and bleed) functions. The introduction of these diverse features in the design is made amenable by the intrinsic characteristics of the integral layout, as exploited in the safety by design approach.

Containing Core Damage. The IRIS is designed so that the reactor cavity floods following any severe accident event that may have the potential for core uncovery and melting. The objective of this cavity flooding action is to prevent reactor vessel failure and subsequent relocation of molten core debris into the containment. Retention of the debris in the vessel significantly reduces the uncertainty in the assessment of containment failure and radioactive release to the environment due to ex-vessel severe accident phenomena. Again, it must be emphasized that IRIS is designed to avoid core uncovery and consequently melting, under all accident conditions. The capability of in vessel core retention is an added feature.

6.2 Safety systems and features (active, passive, and inherent)

The use of passive safety systems provides improvements in plant simplification, safety, reliability, and investment protection over conventional plant designs. The IRIS follows the AP600/AP1000 approach and uses passive safety systems to improve the safety of the plant and to satisfy safety criteria of regulatory authorities. The passive safety systems require no operator actions to mitigate design basis accidents. Once actuated, these systems rely only natural forces such as gravity and natural circulation for continued operation. No pumps, fans, diesels, chillers, or other active machinery are used. A few simple valves align and automatically actuate the passive safety systems. To provide high reliability, these valves are designed to actuate to their safeguards positions upon loss of power or upon receipt of a safeguards actuation signal. However, they are also supported by multiple, reliable power sources to avoid unnecessary actuations.

The IRIS passive systems design takes full advantage of the safety by design approach and the consequent elimination of some postulated design basis events (large LOCAs) and the inherent mitigation of several other (steam generator tube rupture, steam line break, locked rotor,…) through the definition of a safety strategy that is specifically tailored to respond to those remaining accident initiators, that are the more important contributors to core damage frequencies. This design approach allows the licensing safety criteria to be satisfied with a greatly simplified plant design.

The passive safety systems provide a major enhancement in plant safety and investment protection as compared with conventional plants. They establish and maintain core cooling and containment integrity indefinitely, with no operator or ac power support requirements. The passive systems are designed to meet the single-failure criteria, and probabilistic risk assessments (PRAs) are used to verify their reliability.

The IRIS passive safety systems are even simpler than previous passive safety designs since they contain significantly fewer components, reducing the required tests, inspections, and maintenance, require no active support systems, and their readiness is easily monitored.

Passive Core and Containment Cooling

IRIS has a unique method for mitigating the consequences of postulated accidents. The IRIS passive systems configuration is presented in Figure 5, and includes:

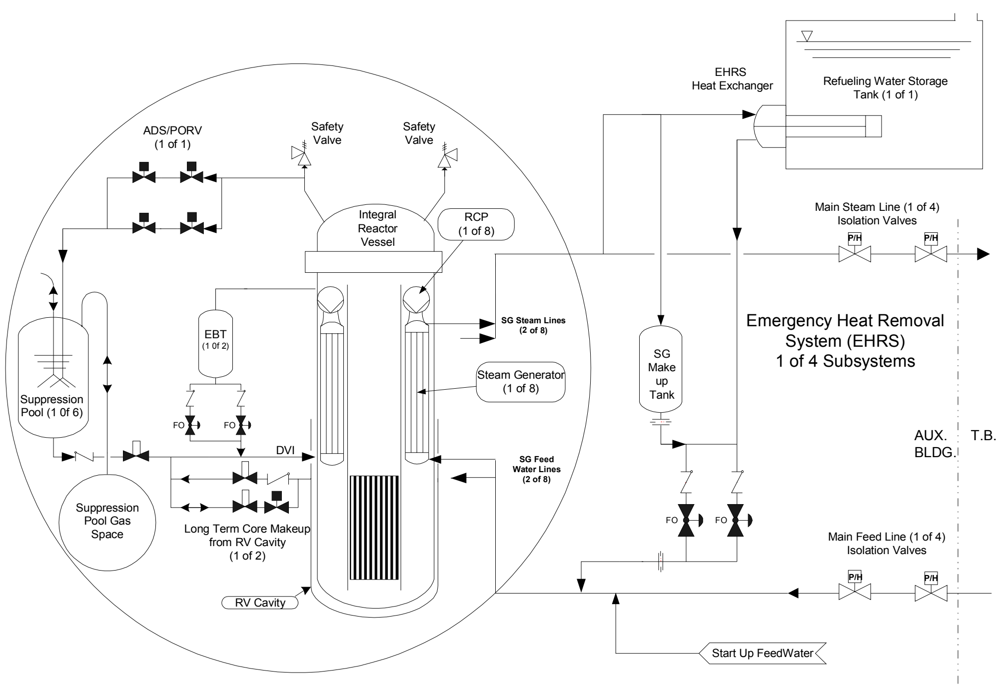

Figure 5 Passive core and containment cooling system

- A passive emergency heat removal system (EHRS) made of four independent trains, each includes a horizontal, U-tube heat exchanger located in the Refueling Water Storage Tank (RWST) located outside the containment structure that is connected to a separate SG feed/steam line.. The RWST provides the heat sink for the EHRS heat exchangers. The EHRS is sized so that a single train can provide decay heat removal in the case of a loss of secondary system heat removal capability. The EHRS operates by natural circulation removing heat from the primary system through the steam generators heat transfer surface, condensing the steam produced in the EHRS heat exchanger, and transferring the heat to the RWST, and returning the condensate back to the SG. The EHRS provides the main post-LOCA depressurization (depressurization without loss of mass) and coolant makeup function for IRIS because it condenses the steam produced by the core directly inside the reactor vessel minimizing the break flow, while transferring the decay heat to the environment, thus performing the functions of both core cooling and containment depressurization;

- Two compact (450 ft^3) full-system pressure emergency boration tanks (EBTs) which deliver emergency boration through the direct vessel injection (DVI) lines for transient events. By their operation these tanks also provide a limited gravity feed makeup water to the primary system;

- A small automatic depressurization system (ADS) from the pressurizer steam space, which assists the EHRS in depressurizing the reactor vessel when/if the reactor vessel coolant inventory drops below a specific setpoint. This ADS has one stage and consist of two parallel 4 inch lines, with two normally closed valves. The single ADS line downstream of the closed valves discharges into the pressure suppression system pool tanks through a sparger. This ADS function ensures that the reactor vessel and containment pressures are equalized in a timely manner limiting the loss of coolant and thus preventing core uncovery following postulated LOCAs;

- A containment Pressure Suppression System (PSS) which consists of 6 water tanks and a common tank for non-condensable gas storage. Each suppression water tank is connected to the containment atmosphere through a vent pipe connected to a submerged sparger to condense steam released in the containment following a loss of coolant or steam/feed line break accident. The suppression system limits the peak containment pressure following a blowdown event to less than the containment design pressure. The suppression system water tanks also provide an elevated source of water that is available for gravity injection into the reactor vessel through the DVI lines in the event of a loss of coolant accident (LOCA);

- A specially constructed lower containment volume that collects the liquid break flow as well as any condensate from the containment in a cavity where the reactor vessel is located. During a LOCA, the cavity floods above the core level, creating a gravity head of water sufficient to provide coolant makeup to the reactor vessel through the DVI lines.

Thus the IRIS passive systems provides the same safety functions as the active systems in current reactors and as the AP600/AP1000 passive systems. As the AP600/AP1000, the IRIS safety system design uses natural gravitational forces instead of active components such as pumps, fan coolers or sprays and their supporting systems.

The safety strategy of IRIS provides a diverse means of core shutdown by makeup of borated water from the EBT and core cooling and heat removal to the environment through the EHRS in the event that normally available active systems are not available. In the event of a significant loss of primary-side water inventory, the primary line of defense for IRIS is represented by the large coolant inventory in the reactor vessel and the fact that in IRIS depressurization is attained with very limited loss of mass, thus maintaining a sufficient inventory in the primary system and guaranteeing that the core will remain covered for all postulated LOCAs. The EBT is capable of providing some primary system injection at high pressure, but the IRIS strategy relies on "maintaining" coolant inventory, rather than "injecting" makeup water. This strategy is sufficient to ensure that the core remains covered with water for an extended period of time (days and possibly weeks). Of course, when the reactor vessel is depressurized to near containment pressure, gravity flow from the suppression system and from the reactor will maintain the coolant inventory for an unlimited period of time. However, this function would not be strictly necessary for any reasonable recovery period since the core decay heat is removed directly by condensing steam inside the pressure vessel, thus preventing any primary water from leaving the pressure vessel.

The systems described above perform the functions of the passive core cooling system (PXS), the ADS, and of the passive containment cooling (PCS) of the AP600/AP1000 family of reactors.

Main control room habitability system

The main control room habitability system (VES) provides fresh air, cooling, and pressurization to the main control room (MCR) following a plant accident. Operation of the VES is automatically initiated upon receipt of a high MCR radiation signal, which isolates the normal control room ventilation path and initiates pressurization. Following system actuation, all functions are completely passive. The VES air supply is contained in a set of compressed air storage tanks. The VES also maintains the MCR at a slight positive pressure, to minimize the infiltration of airborne contaminants from the surrounding areas.

The IRIS VES is analogous to the AP600/AP1000 VES.

Containment isolation

IRIS containment isolation follows the AP600/AP1000 design philosophy and is significantly improved over that of conventional PWRs. One major improvement is the large reduction in the number of penetrations. Furthermore, the number of normally open penetrations is significantly reduced. There are no containment penetrations required to support post-accident mitigation functions.

Long-term accident mitigation

A major safety advantage of IRIS versus current PWRs is that long-term accident mitigation is maintained without operator action and without reliance on offsite or onsite ac power sources. Existing plants rely on operator actions for both short-term and long-term mitigation and are powered from either onsite or offsite ac power sources. The passive safety systems are designed to provide long-term core cooling and decay heat removal without the need for operator actions and without reliance on the active nonsafety-related systems for 7 days.

Deterministic Design Basis

The application of the safety by design approach to IRIS has led to a design that presents several innovative features with regards to the response to transients and postulated accidents. The main effects of this approach on IRIS safety were listed in Table X.X-2 and X.X-3 and are discussed here in some detail:

- **Loss of Coolant Accidents – LOCAs.** The integral layout eliminates by design the possibility of large break LOCAs, since no large primary system piping is present in the reactor coolant system. Also, the probability of small break LOCA is lessened because of the drastic reduction in overall piping length, and the largest primary piping is limited to a diameter of less than 4 in. To cope with postulated small break LOCA, an innovative strategy has been develop to fully exploit the IRIS design characteristics and is illustrated in Figure 6.

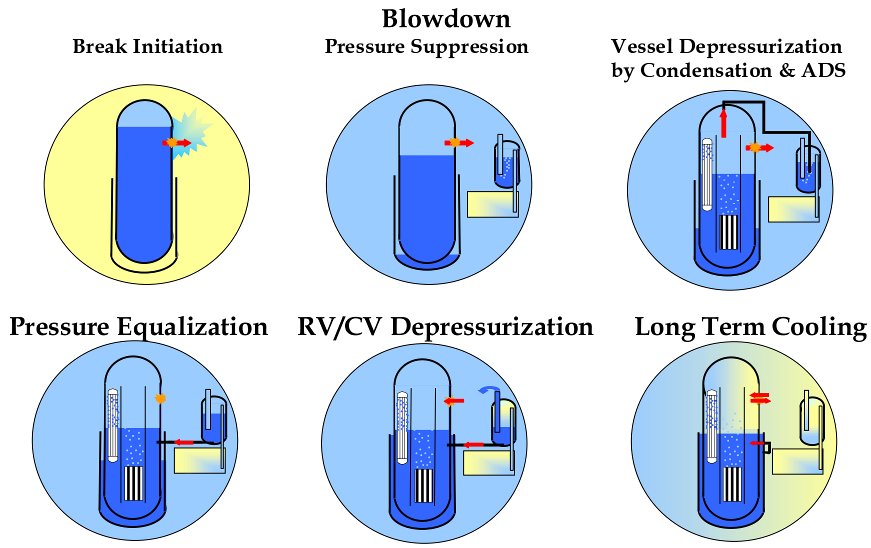

Figure 6: Overview of IRIS response to loss of coolant accidents

IRIS is designed to limit the loss of coolant from the vessel rather than relying on active or passive systems to inject water into the RV. This is accomplished by taking advantage of the following three features of the design:

(1) The initial large coolant inventory in the reactor vessel;
(2) The EHRS which removes heat directly from inside the RV thus depressurizing the RV by condensing steam, rather than depressurizing by discharging mass;
(3) The compact, small diameter, high design pressure containment that assists in limiting the blowdown from the RV by rapidly equalizing the vessel and containment pressures.

After the LOCA initiation, the reactor vessel (RV) depressurizes and loses mass to the containment vessel (CV) causing the CV pressure to rise (Blowdown phase). The mitigation sequence is initiated with the reactor trip and pump trip; the EBTs are actuated to provide boration; the EHRS is actuated to depressurize primary system by condensing steam on the steam generators (depressurization without loss of mass); and finally the ADS is actuated to assist the EHRS in depressurizing the RV. The containment pressure is limited by the Pressure Suppression System and the reduced break flow due to the EHRS.
At the end of the blowdown phase the RV and CV pressure become equal (pressure equalization) with a CV pressure peak <8 bar_g. The break flow stops and the gravity makeup of borated water from suppression pool becomes available.
The coupled RV/CV system is then depressurized (RV/CV depressurization phase) by the EHRS (steam condensation inside the RV exceeds decay heat boiloff). In this phase the break flow reverses since heat is removed not from the containment, but directly inside the vessel: the CV pressure is thus reduced following the RV depressurization as steam from the containment is condensed inside the pressure vessel. As the containment pressure is reduced, a portion of suppression pool water is pushed out through the vents and assists in flooding the vessel cavity.
The depressurization phase is followed by the long term cooling phase (RV and CV pressure reduced to <2 bar_g in <12 hours), during which the gravity makeup of borated water from both suppression pool and RV cavity are available as required. Since decay heat is directly

removed from within the vessel, the long term break flow does not correspond to the core decay heat, but in fact it is limited to only the containment heat loss.

- **Steam Generator Tube Rupture.** In IRIS, the steam generator tubes are in compression (the higher pressure primary fluid is outside the tubes) and the steam generators headers and tubes are designed for full external reactor pressure. Thus, tube rupture is much less probable and if it does occur there is virtually no chance of tube failure propagation. Beside reducing the probability of the event occurrence, IRIS also provides by design a very effective mitigation to this event. Since the steam generators, the feed and steam piping and the isolation valves are designed for full reactor coolant system pressure, a tube rupture event is rapidly terminated by closure of the main steam and feed isolation valves upon detection of the failure. Once the isolation valves are closed, no release of radioactivity (primary fluid) will be possible, and the primary water will simply fill the faulted steam generator. Given the limited volume of the steam generators and piping, no makeup will be necessary to prevent core uncovery. Compared to current and advanced PWRs, with this IRIS response to a tube rupture no steam generator overfill-overpressure-water relief/safety valve failure, resulting in unisolable containment bypass scenario, is possible. Also, the number of tubes assumed to fail has a limited effect on the system response and does not impact the final plant state.

- **Increase in Heat Removal from the Primary Side.** The limited water inventory in the once through steam generator has an important effect on the events in this category. Increases in heat removal due to increased steam flow are eliminated since the steam flow from the once-through steam generators cannot exceed feed water flow rate. Also, the consequence of a design basis steam line break events are lessened. Not only is the impact on the containment limited by the reduced discharge of mass/energy, but also no return to power due to the cooldown of the primary system is possible.

- **Decrease in Heat Removal from the Secondary Side.** Events in this category (loss of offsite power, loss of normal feedwater, turbine trip, feed system piping failure,…) could have larger consequences in IRIS than in loop type PWRs because of the limited water inventory in the once through steam generators. However, this is more than balanced by the large thermal inertia in the primary system (IRIS water inventory on a coolant-per-MWt basis is more than 5 times larger than other advanced passive PWRs), and by the large steam volume in the IRIS pressurizer (steam volume-to-power ratio is more than 5 times that of the AP1000). The reactor trip setpoint is rapidly reached on a low feedwater signal, and the EHRS connected to the steam generators effectively removes sufficient heat to prevent any pressurizer overfill or high pressure relief from the reactor vessel to the containment.

- **Decrease in Reactor Coolant Flow Rate.** The IRIS response to a complete loss of coolant flow is comparable to that of the AP600/AP1000. For the design basis Locked Rotor event, IRIS response is improved over other PWRs by the increased number of pumps, which reduces the relative importance of a loss of a single pump flow. This design choice allows IRIS to prevent fuel damage (i.e. no departure from nucleate boiling) following a postulated locked rotor event even without a reactor trip.

- **Spectrum of Postulated Rod Ejection Accidents.** The integral reactor vessel has a large volume above the core that can be utilized by locating the control rod drive mechanisms (CRDMs) inside the vessel. This in-vessel CRDM location would eliminate the rod ejection accident by design. Additionally, the operational failures associated with the vessel head penetrations would also be eliminated since there are no large drive line penetrations. Some integral reactor designs already feature internal CRDMs, including the Argentinean CAREM and Chinese NHR which employ hydraulically driven rods, and the Japanese MRX which uses an electromagnetic drive mechanism. However, the internal CRDMs have still not been proven for larger reactors and their state of development is incompatible with the current IRIS schedule. Thus, the reference IRIS design features a traditional drive mechanism. The development of in vessel CRDMs is actively being pursued and the option is left open to modify the reference design if warranted by technical developments.

- **Increase in reactor coolant inventory.** This category of events is all but eliminated in IRIS since the IRIS does not utilize high pressure coolant injection following a LOCA.

6.3 Severe accidents (Beyond design basis accidents)

<u>In-vessel retention of molten core debris</u>
The IRIS is designed to provide in-vessel retention (IVR) of core debris by depressurizing and cooling the outside of the reactor vessel following severe accidents. With the reactor vessel intact and debris retained in the lower head, phenomena that may occur as a result of core debris being relocated to the reactor cavity are prevented. The IRIS has reactor vessel insulation that promotes in-vessel retention and surface treatment that promotes wetability of the external surface.
The design features of the containment ensure flooding of the vessel cavity region during accidents and submerging the reactor vessel lower head in water. Liquid effluent released through the break during a LOCA event is directed to the reactor cavity. The IRIS design also includes a provision for draining part of the pressure suppression system (PSS) water tanks water into the reactor cavity.

The IRIS design also includes a second means of containment cooling should cooling via the EHRS be defeated. In this event direct cooling of the containment outer surface is provided and containment pressurization is limited to less than its design pressure. This cooling plus multiple means of providing gravity driven makeup to the core provides a diverse means of preventing core damage and ensuring containment integrity and heat removal to the environment.

7 PLANT LAYOUT

7.1 Buildings and structures, including plot plan

Two plant arrangements of multiple IRIS reactor units and twin units (two reactors each) have been considered to establish the IRIS site plot plans. These site plans are based on preliminary layouts of the major buildings and further optimization will certainly occur. This optimization effort will focus on increasing the shared facilities and systems not only within a twin unit but also sharing between single reactor units and twin units. The data provided here should be considered as preliminary enveloping data, to be optimized as part of the ongoing IRIS design development program with the aim of reducing the plant overall footprint. This optimization will increase the amount of shared equipment between units with the goal of establishing a single, centralized, control and protection building for all the units on a given site.

Preliminary site plot plans are shown in Figures 7 and 8 for a three single unit and a two twin unit IRIS arrangement option, respectively.

- Independent Multiple Single Unit Arrangement – The three single unit arrangement (Figure 7) shows three independent IRIS reactor plants that are completely independent with their own non-safety related service water and main circulating water mechanical draft cooling towers. This arrangement is based on the assumption that the units would be constructed in

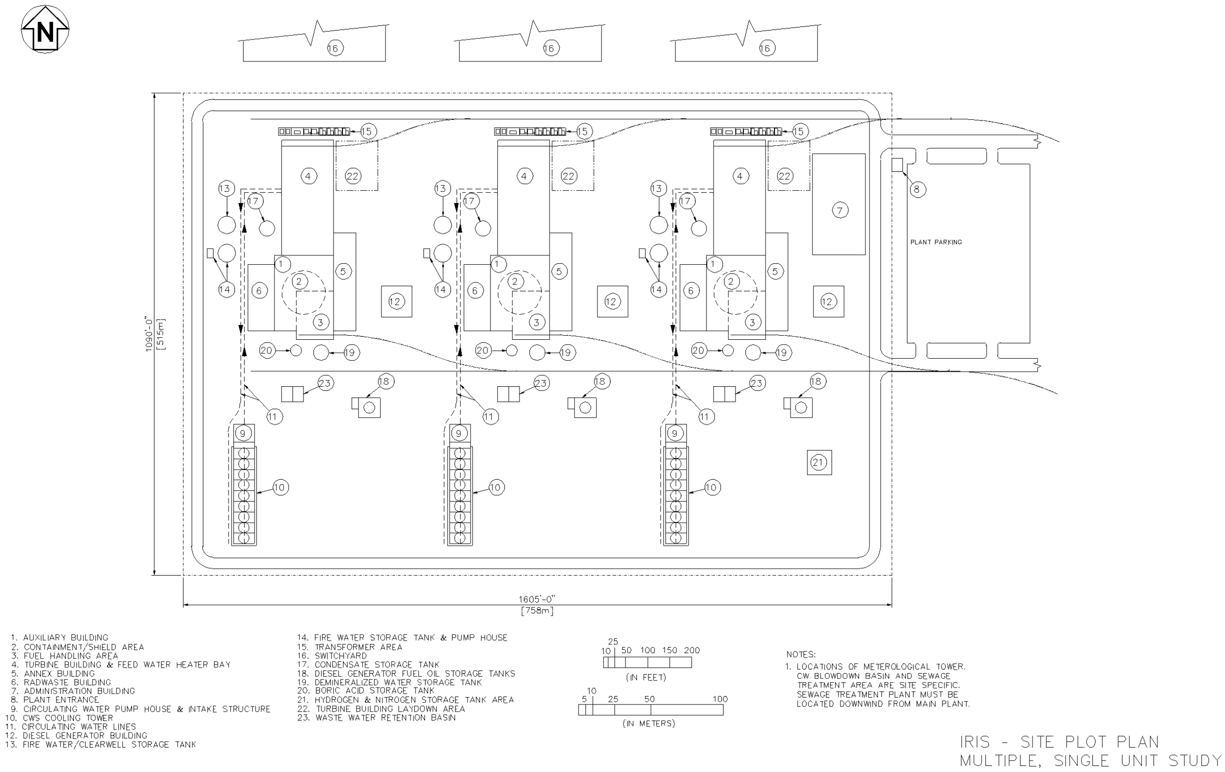

Figure 7 IRIS, Three Single Unit Site Plot Plan

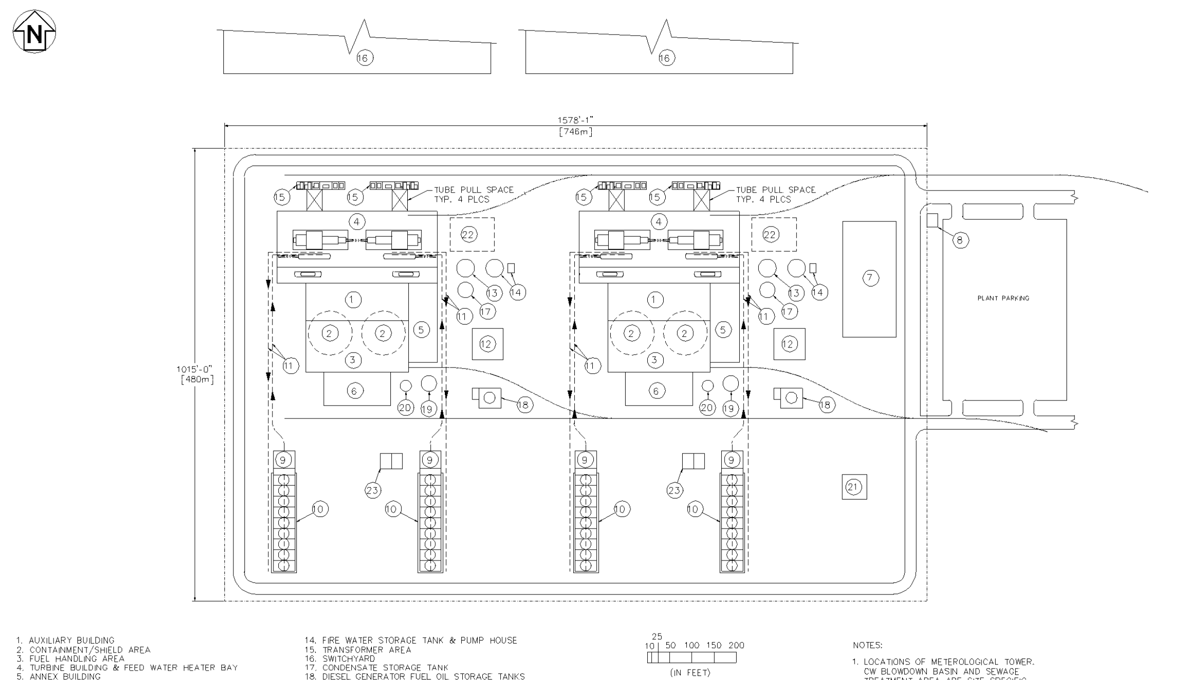

Figure 8 IRIS, Two Twin-Unit Site Plot Plan

series in a "slide-along" manner. The units would be started up in sequence as construction, pre-operation testing, fuel load, and startup testing are all completed for a unit. The right-most completed unit could be operated while construction of the subsequent left-most unit(s) is still in progress, by establishing a temporary exclusion zone between the operating unit(s) and the unit(s) under construction. This arrangement and construction sequencing is aimed at minimizing the construction time of a unit and at providing the utility with generating capability as soon as possible. Other advantages of this slide-along construction method are envisioned to be shorter construction time for the subsequent units by taking advantage of the experience of the work force. In order to accomplish this in series construction, the units are spaced sufficiently apart so that the exclusion zone associated with the operating unit(s) can be established.

- Multiple Twin-Unit Arrangement – The two twin-unit arrangement (Figure 8) shows two independent, twin unit reactors. This arrangement is aimed at maximizing shared components between the two reactors comprising one twin-unit, yet maintaining the ability to initiate operation of a completed twin-unit while construction of subsequent twin(s) proceeds in a "slide-along" manner. Each twin-unit is completely independent from the subsequent twin(s) and each reactor within a twin has its own turbine generator, condenser, and feed and steam systems, contained in a single T/G building with their own non-safety service water and main circulating water mechanical draft cooling towers. However, within a twin-unit, many systems, functions, and physical facilities are shared including: (back to back) control rooms, fuel handling area with refueling machine and spent fuel pit and cask loading facility, radwaste treatment, support systems, and switchyard. Within the twin-unit, separate safety grade power supplies, protection cabinets and switchgear, and electrical systems are maintained.

Plant Arrangement
The current preliminary plant arrangement for the site plan (Figures 7 and 8) has established the bottom of the basemat of the seismic block at –15 meters. The plant grade level is at 0 meters. This seismic basemat includes the containment and shield structure (Item 2, see Figures 7 and 8), surrounded by the auxiliary building which includes the control room and all safety related equipment and fuel handling equipment (Item 1, see Figures 7 and 8). The roof elevation of the auxiliary building, which surrounds and covers the containment and shield building is at +32 meters above grade. The fuel handling area (Item 3) occupies the southern portion of the auxiliary building and extends over the containment such that the containment and RV closure heads can be lifted vertically and stored in the fuel handling area during refueling operations (see Figure 7).

Single Unit (see Figure 7)

- Auxiliary Building (Item 1) – The IRIS auxiliary building encompasses the containment and shield structure as well as the fuel handling facilities and equipment and is founded on a common basemat with the containment/shield. It also contains typical auxiliary building features such as the main control room, the steam and feed water piping penetration area and isolation valves, safe shutdown panel, and all safety related equipment including batteries for electrical power. The auxiliary building has a base of 58 x 41 meters and it extends from the basemat bottom to a roof elevation of +32 meters.

- Containment and Shield Structure (Item 2) – The IRIS spherical steel containment is 25 meters in diameter and is surrounded by a cylindrical concrete shield building, which has an OD of 30 meters and extends from the lowest floor level at elevation –13 meters to +13 meters. The latter is the elevation at the bottom of the refueling cavity.

- The Fuel Handling and Storage Area in the auxiliary building (Item 3) occupies most of the southern above grade position of the auxiliary building and includes a refueling cavity above the reactor/containment closure head. This area includes the spent fuel pit, cask loading and washdown pits, refueling machine, new fuel storage area, heavy lift crane, laydown area, and rail-car loading bay.

- Turbine Building (Item 4) – The IRIS turbine building contains all the equipment associated with the power plant steam and feed water systems and power generation equipment. It is a non-seismic building and contains no safety related equipment. The turbine and generator have been sized based on a 1000 MWt (335 MWe) reactor power. The building dimensions are 80 X 36 meters.

- The Annex Building (Item 5) – The IRIS annex building is a non-seismic, non-safety related structure that houses access control for both the auxiliary and turbine buildings, health physics, technical support center, and non-safety related equipment. This building is constructed at grade and its dimensions are 84 X 15 meters.

Twin Unit (see Figure 8)

- Auxiliary Building (Item 1) – The IRIS twin-unit auxiliary building encompasses the two containment and shield buildings as well as the shared fuel handling facilities and equipment and is founded on a common basemat. It contains typical auxiliary building features, including the shared back-to-back main control room, a steam and feed water piping penetration area and isolation valves for each reactor, safe shutdown panels, and all safety related equipment including batteries for electrical power. Separation between the safety related equipment for the two reactors is maintained throughout the building; this equipment can only be accessed via the main control room area. The twin-unit auxiliary building has a base of 60 x 70 meters and it extends from the basemat bottom to a roof elevation of +32 meters.

- Containment and Shield Structure (Item 2) – Each IRIS reactor is located in a spherical steel containment that is 25 meters in diameter and is surrounded by a cylindrical concrete shield, which has an OD of 30 meters and extends from the lowest floor elevation (at elevation -13 meters) up to the bottom of the refueling cavity (+ 13 meters). Two reactors and their containment/shields are on the auxiliary building share common basemat.

- The Fuel Handling and Storage Area (Item 3) occupies most of the southern above grade, portion of the auxiliary building and includes a refueling cavity above each reactor/containment closure head, while all other capabilities are shared. This includes the spent fuel pit, cask loading and washdown pits, refueling machine, new fuel storage area, heavy lift crane, laydown area, and rail-car loading bay.

- Turbine Building (Item 4) – The twin-unit IRIS has a single turbine building that contains all the equipment associated with the power plant steam and feed water systems and power generation equipment. It is a non-seismic building and contains no safety related equipment. Separate turbine generators and steam and feed systems are provided for each reactor and each is sized based on the single 1000 MWth (335 MWe) reactor power. The building dimensions are 110 X 50 meters. The turbine generator building is arranged such that the two generators are facing and their electrical output equipment is centrally located.

- The Annex Building (Item 5) – The twin-unit IRIS annex building is a non-seismic, non-safety related structure that houses access control, health physics, technical support center, and non-safety related equipment. This building is constructed at grade and its dimensions are 60 x 15 meters and extends to the turbine building.

8 TECHNICAL DATA

General plant data

Power plant output, gross		MWe
Power plant output, net	335	MWe
Reactor thermal output {core power 1000 MWt]	1002	MWt
Power plant efficiency, net		%
Cooling water temperature		°C

Nuclear steam supply system

Number of coolant loops	Integral RCS	
Primary circuit volume, including pressurizer	455	m^3
Steam flow rate at nominal conditions	503	kg/s
Feedwater flow rate at nominal conditions	503	kg/s
Steam temperature/pressure	317/5.8	°C/MPa
Feedwater temperature/pressure	224/6.4	°C/MPa

Reactor coolant system

Primary coolant flow rate	4700	kg/s
Reactor operating pressure	15.5	MPa
Coolant inlet temperature, at core inlet	292	°C
Coolant outlet temperature, at riser outlet	328.4	°C
Mean temperature rise across core	38	°C

Reactor core

Active core height	4.267	m
Equivalent core diameter	2.413	m
Heat transfer surface in the core	2992	m^2
Fuel inventory	48.5	t U
Average linear heat rate	9.97	kW/m
Average fuel power density	20.89	kW/kgU
Average core power density (volumetric)	51.26	kW/l
Thermal heat flux, Fq	2.60	
Enthalpy rise, F_H	1.65	
Fuel material	Sintered UO_2	
Fuel assembly total length	5207	mm
Rod arrays	square, 17x17	
Number of fuel assemblies	89	
Number of fuel rods/assembly	264	
Number of control rod guide tubes	25	
Number of structural spacer grids	10	
Number of intermediate flow mixing grids	4	
Enrichment (range) of first core	2.6-4.95	Wt % U-235
Enrichment of reload fuel at equilibrium core	≤ 5.0	Wt %U-235
Operating cycle length (fuel cycle length)	30-48	months
Average discharge burnup of fuel (nominal)	40000-65000	MWd/t
Cladding tube material	ZIRLO™	
Cladding tube wall thickness	0.57	mm
Outer diameter of fuel rods	9.5	mm
Overall weight of assembly		kg
Active length of fuel rods	4267	mm
Burnable absorber, strategy/material	IFBA and Er	
Number of control rods	37	
Absorber rods per control assembly	24	
Absorber material	Ag-In-Cd (black), Ag-In-Cd/304SS (gray)	
Drive mechanism	Magnetic jack	
Positioning rate [in steps/min or mm/s]	45 steps/min	
Soluble neutron absorber	Boric acid	

Reactor pressure vessel

Cylindrical shell inner diameter	6210 mm	
Wall thickness of cylindrical shell	285 mm	
Total height	21300 mm	
Base material: cylindrical shell	Carbon steel	
RPV head	Carbon steel	
Liner	Stainless steel	
Design pressure/temperature	17.2/360	MPa/°C

Transport weight (lower part), and	1045	t
RPV head	167	t

Steam generators

Type	IRIS 125, vertical, helical coil	
Number [Thermal capacity 125 MWt]	8	
Heat transfer surface	1150	m^2
Number of heat exchanger tubes	656	
Tube dimensions	17.5/13.2	mm
Shroud outer diameter	1640	mm
Total height	8500	mm
Transport weight	35	t
Shroud and tube sheet material	Stainless steel	
Tube material	Inconel 690-TT	

Reactor coolant pump

Type	Spool Type, Canned motor	
Number	8	
Design pressure/temperature	17.2 /343.3	MPa/°C
Design flow rate (at operating conditions)	587.5	kg/s
Pump head	19.8	m
Power demand at coupling, cold/hot	225 kW	
Pump casing material	N.A.	
Pump speed	1800 rpm	

Pressurizer

Total volume	71.41	m^3
Steam volume: full power/zero power	48.96	m^3
Design pressure/temperature	17.2/360	MPa/°C
Heating power of the heater rods	2400	kW
Number of heater rods	90	
Inner diameter	(RPV Head)	
Total height	(RPV Head)	
Material	(RPV Head)	
Transport weight	(RPV Head)	

Pressurizer relief tank Not applicable

Total volume	
Design pressure/temperature	
Inner diameter (vessel)	
Total height	
Material	
Transport weight	

Primary containment

Type	Pressure Suppression, steel	
Overall form (spherical/cyl.)	spherical	
Dimensions (diameter/height)	25/32	m
Free volume	4540	m^3
Design pressure/temperature (DBEs)	1300/200	kPa/°C
(severe accident situations)	1300/200	kPa/°C
Design leakage rate	0.1	%vol/day
Is secondary containment provided?	Missile Protection and release filtration provided	

Reactor auxiliary systems

Reactor water cleanup, capacity	kg/s
filter type	
Residual heat removal, at high pressure	kg/s
at low pressure	kg/s
Coolant injection, at high pressure	kg/s
at low pressure	kg/s

Power supply systems

Main transformer, rated voltage	kV
rated capacity	MVA
Plant transformers, rated voltage	kV
rated capacity	MVA
Start-up transformer rated voltage	kV
rated capacity	MVA
Medium voltage busbars 6 kV or 10 kV)	
Number of low voltage busbar systems	

Standby diesel generating units: number	
rated power	MW
Number of diesel-backed busbar systems	
Voltage level of these	V ac
Number of DC distributions	
Voltage level of these	V dc
Number of battery-backed busbar systems	
Voltage level of these	V ac

Turbine plant

Number of turbines per reactor	
Type of turbine(s)	
Number of turbine sections per unit	
Turbine speed	rpm
Overall length of turbine unit	m
Overall width of turbine unit	m
HP inlet pressure/temperature	MPa/°C

Generator

Type	
Rated power	MVA
Active power	MW
Voltage	kV
Frequency	Hz
Total generator mass	t
Overall length of generator	

Condenser

Type	
Number of tubes	
Heat transfer area	m^2
Cooling water flow rate	m3/s
Cooling water temperature	°C
Condenser pressure	kPa

Condensate pumps

Number	
Flow rate	kg/s
Pump head	m
Temperature	°C
Pump speed	rpm

Condensate clean-up system

Full flow/part flow	
Filter type	

Feedwater tank

Volume	m3
Pressure/temperature	MPa/°C

Feedwater pumps

Number	
Flow rate	kg/s
Pump head	
Feedwater temperature	°C
Pump speed	rpm

Condensate and feedwater heaters

Number of heating stages	
Redundancies	

9. SUMMARY OF MEASURES TAKEN TO SIMPLIFY DESIGN TO REDUCE COSTS, CONSTRUCTION SCHEDULE AND THE NEED FOR MAINTENANCE, TO ACHIEVE HIGH AVAILABILITY AND FLEXIBILITY OF OPERATION, AND TO IMPROVE THE ABILITY TO PERFORM MAINTENANCE

Previous sections have presented the integral configuration, which is shared by IRIS and other integral primary system reactors, and how IRIS has implemented the safety-by-design approach through exploitation of the integral design features in developing a unique package which greatly improves the reactor response to accident events. Consequently, the IRIS design features significant simplifications even with respect to passive reactor designs, such as the elimination of the need for high pressure core safety injection system and reduction of other safety systems, which will result in both improved safety and economics.

Another characteristic of IRIS is the capability of operating with long life, straight burn cores. Even though the reference design features a two-batch three year fuel cycle, selected on the basis of ease of licensing and U.S. utilities preference, IRIS is capable of operating in straight burn with a core lifetime of about 8 years. However, the significant advantages connected with a long refueling period in reducing operation and maintenance (O&M) costs is lost if the reactor still has to be shut down on a 18 to 24 months cycle for routine maintenance and inspection. Thus, first and foremost, the IRIS primary system components are designed to have very high reliability to decrease the incidence of equipment failures in order to reduce the frequency of required inspections or repairs. Next, IRIS has been designed to extend the need for scheduled maintenance outages to at least 48 months. The basis of the design has been a study performed in the mid to late 90's by MIT for a PWR power station to identify required actions for extending the maintenance period from 18 to 48 months. The strategy was to either extend the maintenance/testing items to 48 months or to perform maintenance/testing on line. MIT identified for 3743 maintenance items, 2537 of them off-line and the remaining 1206 on-line. It was also found that 1858 of the off-line items could be extended from 18 to 48 months, while 625 could be recategorized from off-line to on-line. This left only 54 items which still needed to be performed off-line on a schedule shorter than 48 months. Starting from this MIT study and factoring in the specific IRIS conditions (for example, there is no need to change the pumps oil lubricant, since the spool type reactor coolant pumps are lubricated by the reactor coolant), only 7 items were left as obstacles to a 48-month cycle. They have been or are being resolved.

Because of the four-year maintenance cycle capability, the capacity factor of IRIS is expected to comfortably satisfy and exceed the 95% target, and personnel requirements are expected to be significantly reduced. Both considerations will significantly decrease the O&M costs.

Uninterrupted operation for 48 months requires reliable advanced diagnostics. The IRIS project is currently investigating various technologies, either already proven or in advanced phase of development, to monitor the behavior of the in-core components. Promising, but more distant technologies, are being pursued by affiliated universities.

Finally, IRIS plans to address licensing by relying on the excellent defense in depth provided by the safety-by-design, but also to adopt risk informed regulation based on PRA analyses to achieve further goals including demonstrating that IRIS does not need emergency response planning. This, besides being very attractive to power producers considering IRIS, will also have a very important impact on the public acceptance.

10 PROJECT STATUS AND PLANNED SCHEDULE

The IRIS project started in late 1999. It has completed the trade-off studies and conceptual design and is currently in the preliminary design stage. The project is already enough advanced that in October 2002 it has started its licensing process. Currently activities with the US NRC are limited to a focussed pre-application. Essentially in this first phase of the pre-application licensing, NRC will review the project to provide feedback on two items that are considered as long lead items and therefore critical for the overall project schedule. These two items are identification of necessary testing; and assessment of the risk informed regulation approach.

Licensing activities will intensify following completion of the AP1000 design certification, expected in 2004/2005. Therefore, the current plan is to submit an IRIS design certification application in 2005, with the objective of obtaining design certification in 2008/2009. Following certification, with a parallel first-time-engineering effort, a construction period of three years for the first IRIS module is expected, thus IRIS deployment could be as early as 2012, and more realistically around 2015.