Status report 82 - KERENA™ (KERENA™)

Overview

Full name	KERENA™
Acronym	KERENA™
Reactor type	Boiling Water reactor (BWR)
Coolant	Light Water
Moderator	Light water
Neutron spectrum	Thermal Neutrons
Thermal capacity	3370.00 MWth
Electrical capacity	1290.00 MWe
Design status	Basic Design
Designers	AREVA
Last update	13-04-2011

Description

Introduction

The KERENA™ reactor (renamed in 2009, formerly SWR 1000) blends years of experience in design, construction and operation of BWRs with concepts to achieve an increased safety. It has been developed to provide a reliable source of safe and economically competitive electricity supply.

The KERENA™ reactor is a medium size boiling water reactor. It is an evolutionary development based on the experience gained from the proven engineering of current-generation BWR plants supplemented by an innovative approach that entails the partial replacement of active safety systems with passive safety systems. The passive safety systems utilize basic laws of physics, such as gravity, natural convection and temperature and pressure differentials, enabling these systems to function without electrical power supply or/and actuation by powered instrumentation and control (I&C) systems. The concepts provide passive protection of the core without operator intervention for up to three days.

The current final basic design of KERENA^{TM} is part of a strategic partnership between AREVA NP and the German utility E.ON Kernkraft setup in April 2008, and is based on the above mentioned experience and technologies. This contract considers power output of:

- Reactor thermal power 3 370 MW_{th}
- Net electric output 1 250 MW_{el}

The overall objective is to achieve a high level of safety and reduce or eliminate the risks associated with licensing and construction of a new nuclear power plant while customizing the design and developing an economically competitive plant. The high level of safety is reached by optimizing the combination of active and passive features:

- Safety systems have been simplified by introducing passive safety systems.
- Most nuclear safety functions are performed by active systems with a passive system as backup.
- Accident control is possible with passive safety systems and without overheating the core.
- Passive systems, such as the newly developed Passive Pressure Pulse Transsmitters, function either without an activation system or with a passive activation system.
- High degree of diversity in system and component design.
- Large water volumes in the Reactor Pressure Vessel (RPV), inside containment and outside containment for safety reasons.
- Severe accident mitigation by in-vessel melt retention and passive heat removal from the RPV and the containment.

The adoption of passive safety systems requires extensive engineering effort, planning and layout work to modify previous BWR system designs. The passive safety systems replace and/or supplement the redundant active safety systems, and must be capable of ensuring reliable plant operation and accident control.

In parallel to this, full scale tests are carried out for all passive components to verify the planned properties.

Description of the nuclear systems

2.1. Reactor coolant system and its main characteristics

The reactor coolant system is located in the reactor building and is surrounded by a reinforced concrete containment with an internal steel liner.

Three main steam lines connecting the RPV to the high-pressure turbine section serve to transport the steam generated in the reactor to the turbine. Isolation valves of diverse design are provided in each main steam line inside and outside the containment. The isolation valves are both gate valves, but of different design.

The function of the feedwater system is to receive the water from the main condensate system and to route it to the reactor via two feedwater lines. Isolation valves are provided in each feedwater line inside and outside the containment. The inboard isolation valves are check valves while the outboard isolation valves are gate valves.

The outboard valves in both the main steam lines and the feedwater lines are located immediately adjacent to the containment.

Each main steam line inside the containment is allocated a specific number of safety-relief valves (SRVs) for overpressure protection of the RPV.

For pressure relief, opening of certain SRVs is initiated by a signal from the reactor protection system. If reactor pressure should continue to rise, then all SRVs are mechanically opened by spring-loaded pilot valves. The SRVs close with a corresponding decrease in system pressure.

For automatic depressurization, the SRVs are opened either by solenoid pilot valves or by the passive pressure pulse transmitters (PPPTs) and diaphragm pilot valves, all SRVs being opened at the same time in this case. Half of the SRVs are designed such that they do not reclose after automatic depressurization. This ensures that the pressure in the reactor remains at a low level.

The steam blown down by the valves is routed downwards into the core flooding pools through discharge pipes. These pipes terminate below the surface of the pool water in specially designed T-shaped quenchers.

2.2. Reactor core and fuel design

The KERENA™ core represents an "evolutionary" development based on previously common BWR core designs. While no changes have been made to the basic core structure, certain modifications have been introduced. These include a reduced active core height and an enlarged fuel assembly.

A consequence of reducing the active core height is that the core can be positioned lower down inside the RPV. This provides a larger water inventory inside the RPV above the core, a feature that facilitates accident control.

The above-mentioned modification of the fuel assemblies consisted of enlarging the existing fuel assembly design from a 10x10-9Q rod array (ATRIUM^{TM}10) to a 12x12-16 rod array (ATRIUM^{TM}12). The fuel rod diameter and pitch, on the other hand, remained the same as in the ATRIUM^{TM}10 fuel assembly. As a result of this new design, there are fewer fuel assemblies in the core, which reduces handling times during refueling. Reducing the number of fuel assemblies also reduces the number of control rods, and hence the number of control rod drives as well. The average power density is approximately 51 kW/l.

2.3. Fuel handling and storage systems

There is no significant difference from a functional point of view between the equipment and structures used for refueling, storage of new and spent fuel assemblies and handling of reactor components in the KERENA™ and those found in traditional BWR nuclear power plants.

2.3.1 New fuel storage

New (i.e. unirradiated) fuel assemblies are stored in a new fuel storage area specially provided for this purpose adjacent to the spent fuel pool. The new fuel assemblies are placed in dry storage racks which can accommodate approximately 144 fuel assemblies.

2.3.2 Spent fuel pool

Spent fuel assemblies are stored in the water-filled fuel pool located inside the reactor building on an extension of the axis of the shielding/storage pool and reactor well. The pool water provides for residual heat removal and shielding. The fuel pool has sufficient storage capacity for approximately 1650 fuel assemblies and approximately 50 control rods.

2.4. Main components

2.4.1 Reactor pressure vessel

The RPV surrounds the reactor core and the RPV internals. As part of the reactor coolant pressure boundary (RCPB), the RPV represents an important confinement barrier for preventing the release of radioactive materials. Figure 1 shows the RPV together with its internals and insulation as well as the inner concrete cylinder of the drywell surrounding it.

The RPV consists of a cylindrical section with a spherically dished bottom head, and a hemispherical top head that is flanged to the cylindrical section. The vessel flange protrudes mainly inwards. The vessel top head is bolted to the lower section of the vessel by means of studs.

Welded to the outside of the RPV is a support skirt that accommodates all static and dynamic loads, transmitting them to the inner concrete cylinder of the drywell and thus to the concrete foundation. The entire inside surface of the RPV shell is provided with weld-overlay cladding made of stabilized austenitic stainless steel. The pressure vessel is manufactured from SA 508 Gr. 3 Cl. 1. The alloy composition is specified within a very narrow range to optimize ductility, stresses and resistance to neutron embrittlement.

The RPV has numerous nozzles for connecting the piping of the main steam, feedwater, emergency condenser, shutdown cooling and vessel head spray systems, as well as for accommodating the internal reactor water recirculation pumps, the control rod drives, the core flux monitoring assemblies, and the reactor water level, pressure, and temperature measuring instrumentation.

The four emergency condensers as well as the four standpipes (which connect the passive pressure pulse transmitters and the condensation pots of the RPV level measuring equipment to the reactor vessel) are regarded as being external extensions of the vessel since they are connected to it via nonisolable lines. These components are subject to the same requirements and conditions as those applicable to the RPV.

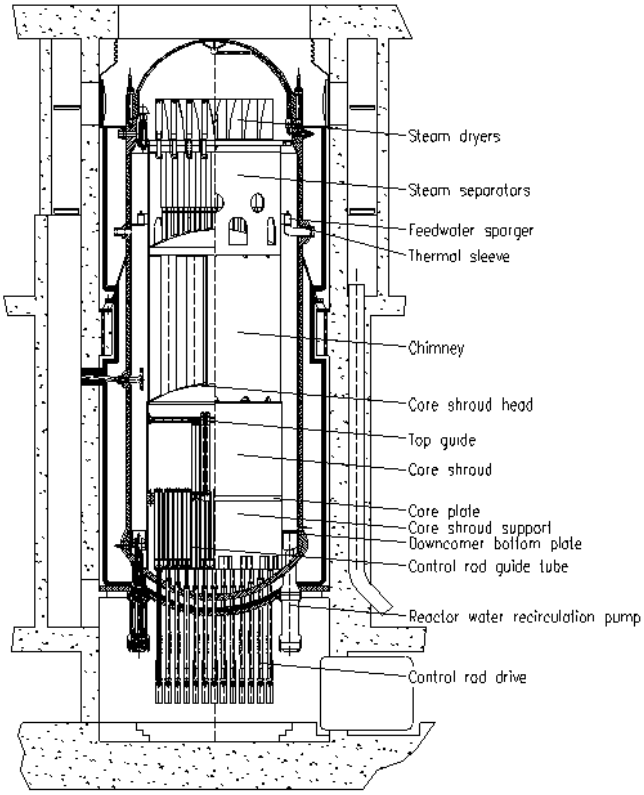

Figure 1: KERENA™ reactor pressure vessel and internals

2.4.2 Reactor internals

The main reactor internals are illustrated in Figure 1. The RPV internals primarily serve to:

- Separate the regions containing coolant from those containing steam;
- Enhance internal circulation of the reactor coolant;
- Provide the necessary flow paths for the circulating coolant;
- Ensure uniform distribution of the feedwater in the downcomer annulus;
- Guide the control rods and the core instrumentation assemblies;
- Direct the flow of the steam-water mixture produced in the reactor core;
- Locate the fuel assemblies in the core;
- Perform phase separation of the steam-water mixture;
- Dry the steam leaving the RPV.

In designing the RPV internals, preference was given to using components and component designs that had already proven their reliability during operation at plants belonging to Siemens' 1969 and 1972 Product Lines. Designs deviating from these were only selected if they resulted in shorter refueling outages or if they were unavoidable due to the large steam-water plenum above the core (i.e. the space between the low-elevation core and the relatively high-elevation steam separators).

All RPV internals are designed for removal and replacement as necessary.

2.4.3 Reactor water recirculation pumps

The eight reactor water recirculation pumps ensure sufficient cooling of the reactor core. Reactor power output can be controlled by varying the speed of the pumps. If one of the pumps should fail, the flow of coolant through the core can be kept constant by increasing the speed of the remaining pumps.

The pumps that have been selected for KERENA™ are so-called wet-motor pumps, where the electric pump motor is situated inside the reactor coolant pressure boundary. This eliminates the need for mechanical seals as well as for an oil-lubricated, combined thrust and journal bearing with its dedicated oil supply system. Moreover, there is no longer any axial thrust induced by the reactor coolant pressure that has to be accommodated.

2.5. Reactor auxiliary systems

The main auxiliary systems of KERENA™ are

- the residual heat removal (RHR) system;
- the reactor water cleanup (RWCU) system;
- the fuel pool cleanup system;
- the fuel pool cooling system.

Apart from these systems many other auxiliary systems, such as waste processing systems, a chilled water system, and HVAC systems, etc. exist for normal operation of the plant.

The KERENA™ design concept includes two active trains for low-pressure core injection/flooding and RHR. As in earlier plant designs these systems perform the following tasks:

- Cooling of the reactor core during and after normal plant shutdown;
- Water transfer operations before and after refueling;
- Operational heat removal from the core flooding pools and the pressure suppression pool;
- Heat removal from the containment in the event of loss of the main heat sink by cooling the pressure suppression pool and core flooding pool water;
- Low-pressure coolant injection into the RPV and simultaneous heat removal in the event of loss-of-coolant accidents.

The system is actuated by safety instrumentation and control (I&C) equipment and their electrical loads are connected to an emergency power supply system.

In KERENA™, unlike in previous BWR plants, a low-pressure concept (standard practice in PWR plants) is applied to the reactor water cleanup system outside the containment. A regenerative heat exchanger and a pressure-reducing station are arranged inside the containment, while another cooler, the cleanup pumps, the reactor water filter-demineralizers and the filter precoating station are all located outside the containment. The purified water is conveyed back into the containment by one of two return pumps and fed to the RPV via the regenerative heat exchanger. The two return pumps also supply cooling water to the control rod drives and seal water to the reactor water recirculation pumps.

The advantage of this concept lies in the fact that the filter-demineralizers, with their large number of connections, and the low-pressure cooler can be positioned outside the containment, and the number of containment penetrations can thus be significantly reduced.

The fuel pool must be cooled, independent of reactor operation, for as long as the removal of decay heat generated by the spent fuel assemblies in the fuel pool is required. In existing BWR plants fuel pool cooling trains are installed for purposes of decay heat removal.

The KERENA™ fuel pool is equipped with two redundant cooler units, each consisting of four heat exchangers operating in parallel, which are installed directly in the fuel pool. The fuel pool water is cooled by means of natural convection. Redundancy is ensured by connecting the cooler units to the redundant closed cooling water system which is backed up by an emergency power supply. The tubular heat exchangers are suspended from the fuel pool wall such that controlled water flow conditions are obtained.

2.6. Operating characteristics

The power plant is controlled using separate control loops (proven design): reactor power is matched to present power requirements by the reactor power controller; the turbine is controlled by a constant main steam pressure being maintained upstream of the turbine by the reactor pressure controller.

The main mechanism employed for reactor power control is that of recirculation flow control which changes the flow of coolant through the core. The control rod follow-up control system keeps the reactor water recirculation pumps in a favorable speed range. The pressure in the reactor is maintained at a constant level using the turbine control valves that adjust the main steam flow from the reactor.

Automatic control of reactor power is possible over the range between 20 and 100% of rated power. Reactor power can be adjusted by about 30% (40% in stretch-out conditions) by changing the core coolant flow rate without repositioning control rods; between 70% and 100% (60% to 100% in strech-out conditions) of rated power. The core coolant flow rate is changed by adjusting the speed of the reactor water recirculation pumps. The speed of the pumps can be manually controlled from the control room. After the automatic mode of control has been selected, the speed of all pumps can be changed by adjusting the power set point.

If required, reactor power can be further controlled by automatic repositioning of control rods between 20% and 70% of rated power. The Reactor Operating Map is shown in Figure 2.

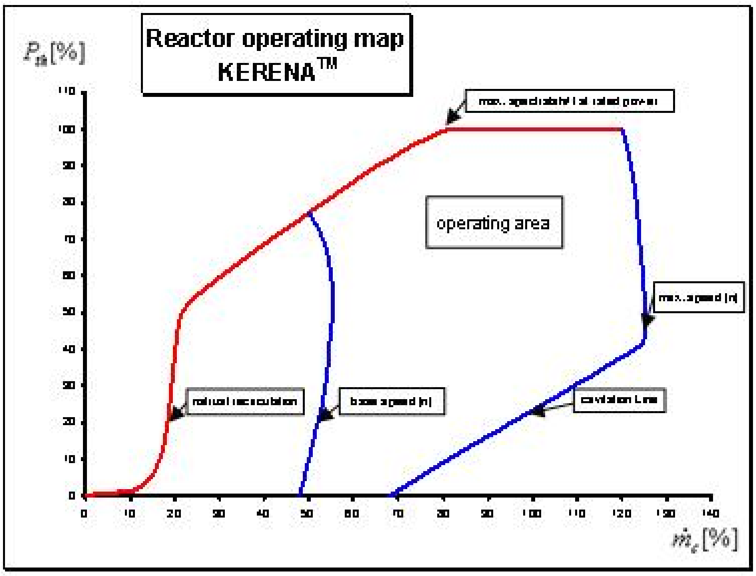

Figure 2: Reactor operating map

Description of safety concept

3.1. Safety requirements and design philosophy

The safety concept of the KERENA™ according to the defense-in-depth concept is based on three fundamental principles:

1. Prevention of accidents and environmental impacts
2. Accident control
3. Mitigation of consequences

First Safety Principle: "Prevention of Accidents and Environmental Impacts"

This first and most important principle is put into practice by imposing stringent requirements on the design and quality of the plant as well as on the qualifications of personnel, i.e. their competence and reliability.

For this purpose, safety-promoting design, manufacturing and operating principles are pursued at the **first level** of safety measures.

According to general experience with technical systems, malfunctions of components or systems leading to off normal operating conditions cannot be entirely ruled out during the service life of a plant, even if the above principles have been observed. In order to control these off normal operating conditions, systems are designed and measures are taken to control and monitor operation such that the occurrence of accidents as a consequence of off normal operating conditions is prevented with an adequate degree of reliability (**second level**).

Second Safety Principle: "Accident Control (Damage Mitigation)"

Despite the precautions taken in compliance with the first safety principle on the two levels described above, it is nevertheless assumed that improbable but hypothetically conceivable accidents may occur during the service life of the nuclear power plant, i.e. accidents that the plant must be designed to control. These accidents – called design basis accidents – include, for example, the following:

- Accidents caused by plant-internal events: main steam line break, feedwater line break, control equipment malfunctions or accidents not involving loss of coolant;
- Accidents due to natural or external man-made hazards: earthquakes or high water levels.

In order to fulfill the second principle, equipment for accident control is provided on a **third level** of safety measures. In the case of the KERENA™, new approaches have been pursued that lead to a significantly higher level of safety.

The safety equipment is designed in such a way that it protects the plant personnel and the population in the vicinity of the plant against the consequences of accidents. For this, the following design principles are applied:

- Redundancy, diversity and independence of subsystems (trains);
- Physical separation of redundant subsystems (trains);
- Safety-oriented system behavior in the case of subsystem or component malfunctions;
- Passive safety functions that are redundant and diverse to active safety functions
- Passive actuation of safety function either due to physical effects (e.g. low level in RPV actuates emergency condenser) or due to PPPTs actuating scram and containment isolation.

Equipment for accident control consists of passive and active safety components.

Passive components, which do not require I&C signals or external power to perform their protective function, take effect solely by virtue of their presence (such as the numerous protective barriers made of concrete or steel) or as a result of basic laws of physics (such as gravity and natural convection). Examples of such equipment are the emergency condenser and the passive pressure pulse transmitter.

Active safety equipment, such as the RHR pumps and the control rods, are controlled and, if necessary, put into operation by the reactor protection system.

In addition to the measures for controlling design basis accidents, features are also provided on a **fourth level** of safety measures to cope with design extended conditions, such as:

- Aircraft crash,
- Explosion pressure waves,
- Combustible and toxic gases,

Third Safety Principle: "Mitigation of Consequencess"

Finally features are also provided on a fifth level of safety measures to mitigate the consequences of severe accidents, such as:

- Core melt.

3.2. Safety systems and features (active, passive and inherent)

3.2.1 Passive equipment for accident control

The fundamentally new concept for accident control incorporated into the KERENA™ design includes passive equipment that, in the event of failure of the active safety equipment, will bring the plant to a safe condition. Passive systems do not need external power and most of them do not need any I&C signals. They are widely used within BWR technology e.g. safety valves. New passive safety equipment is introduced in the KERENA™ design (see Figure 3) which enables in general an enhanced passive accident control as well as a complete passive control of residual heat removal and passive actuation of several safety functions.

Passive safety systems are decribed below:

3.2.2 Emergency condensers (EC)

The function of the emergency condenser system is to remove, in the event of an accident, the decay heat still being generated in the reactor as well as any sensible heat stored in the RPV to the core flooding pools, without any coolant inventory being lost from the RPV. The system thus replaces the high-pressure coolant injection systems used in existing BWR plants. The EC system also provides a means for reactor pressure relief that is diverse with respect to the safety-relief valves.

3.2.3 Containment cooling condensers (CCC)

The task of the four containment cooling condensers is to remove – by entirely passive means – decay heat from the containment following accidents leading to the release of steam inside the drywell, and in this way to limit buildup of containment pressure. They provide redundancy and diversity with respect to the RHR system.

3.2.4 Core flooding system

The core flooding system is a passive low-pressure flooding system for controlling the effects of loss-of-coolant accidents (LOCAs). It is installed at an elevation which ensures that, following automatic depressurization of the reactor, it can passively flood the reactor core by means of gravity flow. The system provides redundancy and diversity with respect to the core flooding function of the RHR system.

3.2.5 Passive pressure pulse transmitters (PPPT)

The PPPT is a completely passive switching device that is used to directly initiate the following safety functions (as a minimum), without the need for I&C equipment: reactor scram, containment isolation at the main steam line penetrations, and automatic depressurization of the RPV. The PPPT comes into action as a result of a drop or increase in reactor water level as well as an increase in reactor pressure. For activating the various safety functions, PPPTs of redundant design are installed at three elevations. The upper PPPTs, situated at an elevation beneath that of the normal water level of the RPV, are responsible for initiating reactor scram. The lower PPPTs, arranged at a lower elevation, activate automatic depressurization of the reactor as well as closure of the main steam containment isolation valves. Further PPPTs installed at appropriate locations respond to a rise in reactor water level above the main steam nozzles and likewise activate reactor scram and containment isolation at the main steam line penetrations.

3.2.6 Active safety systems

In order to control the effects of design basis accidents, each nuclear power plant is equipped on the third safety level with a special safety system consisting of the reactor protection system and the active safety equipment actuated by it. The reactor protection system is a programmable digital I&C system that continuously monitors all important plant operating parameters, initiates safety-oriented actions if specified limits are approached and, in this way, takes control over operational disturbances, thus preventing them from developing into accidents. The postulated design basis accidents can thus be controlled to such an extent through activation of the safety equipment that consequences are restricted to the plant itself.

The response of the reactor protection system is not event-oriented but safety-oriented, an approach that ensures that no potential causes of failures or malfunctions can be overlooked when designing the system. The active safety equipment is mainly comprised of process systems.

As far as the overall safety concept is concerned, it is vitally important that all types of accidents that involve the risk of an increased release of activity to the environment be evaluated.

By far the largest proportion of radioactivity present in the nuclear power plant is located in the reactor core, i.e. contained in the crystal lattice of the fuel and in the fuel cladding tubes. Therefore large releases are only conceivable if these two inner activity barriers should become damaged. The following theoretically conceivable types of accidents involving the risk of an increased release of activity are therefore possible in the event of damage to these two barriers:

- Unallowable rise in reactor power,
- Impaired heat removal from the reactor core,
- Loss of cooling as a result of a loss of coolant.

Among the various active safety systems, a central role is played by the reactor protection system which continuously monitors all important plant operating parameters and, if specified limits are approached, initiates safety actions by actuating other safety equipment as and when required.

The hydraulic scram system employs neutron-absorbing control rods that are kept in the withdrawn position, i.e. at the bottom of the core, during reactor power operation. If a scram is triggered, valves are opened in lines leading to the steam driven scram tanks and the energy stored in these tanks rapidly inserts the control rods into the core from below, thus terminating the chain reaction.

A second, diverse shutdown system is also provided with which the reactor can be shut down by injecting a neutron-absorbing boron solution into the reactor coolant. The injection is performed without any external power using only a high pressure nitrogen buffer.

If a release of radioactivity into the containment is to be expected during an accident, the containment isolation system allows the containment to be isolated from the plant environs. All piping that penetrates the containment wall and belongs to systems not required for accident control can be isolated by containment isolation valves.

The RHR system takes over cooling of the reactor core and/or containment heat removal in the event of an accident.

Finally, mention should be made of the emergency power supply system that supplies power to active safety-related systems if the main generator cannot provide auxiliary power in the event of an accident and if supply from the offsite power system is not available.

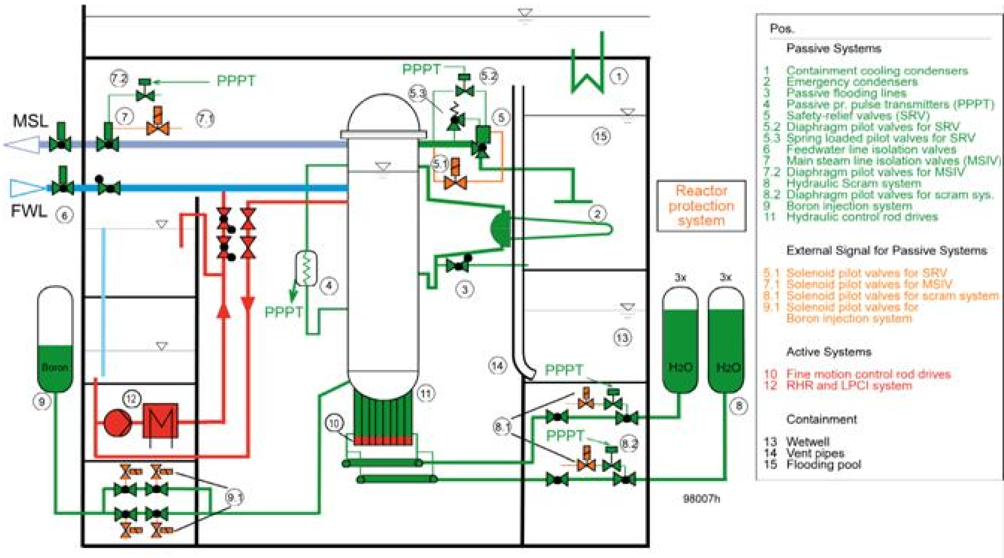

Figure 3: KERENA™ – Active and passive systems

3.3. Severe accidents (beyond design basis accidents)

Severe accidents are those accidents that could lead to core damage states (core melt). For new nuclear power plants it must be ensured that the consequences of such accidents would be limited to the plant itself and that there would be no need for large-scale actions to protect against the harmful effects of ionizing radiation beyond the plant perimeter. Therefore severe accidents are likewise taken into account in plant design despite their extremely low probability of occurrence. In view of the above requirements, the aim of severe accident analysis is to verify that, even if the core should become damaged, no unallowable releases of radioactivity to the plant environs will result.

Loss of all active and passive means of supplying coolant to the RPV as well as of all emergency condensers is assumed for the most severe postulated accident: core melt. To control this accident scenario additional safety systems are planned for the KERENA™ reactor and the plant is designed to withstand the consequences of the accident.

Core melt at high pressure is ruled out by the design of the depressurization system. The melt is retained inside the reactor vessel under low-pressure conditions due to cooling of the RPV exterior. A flooding system is installed for this purpose which feeds water from the core flooding pools into the section of the drywell surrounding the RPV:

3.3.1 Drywell flooding system

A postulated severe accident involving core melt is controlled such that the molten core is retained inside the RPV. For this purpose the section of the drywell surrounding the RPV can be manually flooded (uninterruptible power supply needed) with water in order to cool the RPV exterior and thus remove heat from the reactor.

The drywell flooding line is normally isolated, the valves in this line only being opened when flooding is required. The steam arising during cooling of the RPV exterior is condensed at the containment cooling condensers which transfer the heat from the containment to the water in the shielding/storage pool. The capacity of the shielding/storage pool is such that makeup water does not need to be supplied to the pool until several days after onset of the accident, thus enabling virtually unlimited heat removal.

The containment design is based on the pressure buildup due to the hydrogen arising from a 100% zirconium-water reaction involving the zirconium inventory present in the core. Hydrogen release always occurs via the drywell, and some of this hydrogen is also carried over into the pressure suppression chamber, depending on the given pressure conditions. Any further pressure buildup due to chemical reactions by the hydrogen is not possible since the containment is inerted with nitrogen.

In addition, a filtered venting system prevents any possible overpressurization of the containment.

Proliferation resistance

The KERENA™ renders the diversion or undeclared production of nuclear materials or misuse of technology, by host state very difficult due to inherent technical impediments. On the one hand the declared inventory is not appealing and diversion of either fresh or spent fuel elements is made difficult by design. On the other hand undeclared production of weapon grade materials has a very significant cost and is easily detectable.

4.1. Technical features to facilitate implementation of safeguards

When the reactor is operating the reactor pressure vessel is closed and the fuel is inaccessible. Refueling operation with an open vessel and fuel transfers occur under transparent water shielding permitting direct visual observation for safeguards purposes.

The design of the plant facilitates the implementation of safeguard inspection controls and accounting measures that constitute extrinsic barriers enforcing the institutional agreements and policies.

Refueling operation and associated fuel movements are conducted at a low frequency and take place only in the reactor building that can easily be monitored. Their integrity is ensured by their structure, designed against external hazards. The few access points allow monitoring and surveillance of all passages.

The KERENA™ design includes necessary safeguard measures virtually eliminating any risk of proliferation of fissile materials.

4.2 Intrinsic features and extrinsic measures that ensure enhanced protection against nuclear material theft and misuse

4.2.1 Fuel assemblies

The KERENA™ is designed for operation with fissile material that has a slender proliferation interest.

Fuel assemblies make use of

- enriched uranium fuel (LEU), the enrichment is lower than 5% U235 thus far below "Weapon-grade" or
- Mixed Oxide fuel (MOX) a uranium-plutonium mixture with ca. 6 % PUfissile is coming from reprocessing of spent fuel elements

Diversion of fuel assemblies for use as feed in enrichment devices and/or diversion of fresh MOX assemblies for processing to separate plutonium are made extremely difficult. A fuel assembly weighs more than half a metric ton and requires a specific equipment to be lifted. Furthermore the fuel assemblies are handled and stored in the reactor building which is protected by a heavy shielding and has limited and controlled access.

4.2.2 Spent fuel

Spent fuel which has gone through a normal operating life will reach a high burn up (ca. 60 MW d/kg), so it is of limited interest for proliferation purpose: the U235 content is below 1% and the poor isotopic quality of the plutonium leads to high neutron emission rate, high heat emission and high level of radiation.

In the spent MOX fuel assembly, the remaining plutonium content has an even worst isotopic quality, and thus a further reduced attractiveness.

In both cases, the spent fuel is highly radioactive and would require a heavily shielded cask to be moved, therefore theft is unrealistic.

Fuel assembly design allows disassembly with a specific device implemented in the fuel pool. This may result in presence of individual fuel rods in the reactor building; however they may be easily safeguarded by surveillance.

Safety and security (physical protection)

5.1. Objectives of Protection

The objectives of Physical Protection for KERENA™ are:

- prevent theft or manipulation of nuclear material
- enable safe shutdown of the plant in case of a malevolent act
- provide strict separation of redundant trains
- apply a defense-in-depth protection

5.2.1. Concept

The basis for protection measures is to define safety relevant systems, components and equipment (vital equipment) necessary for a safe shutdown of the plant and residual heat removal.

To protect vital equipment inside the plant, different areas are defined representing lines-of-defense (barriers) each with a specific resistance against malevolent acts, which enable the application of a protection concept according to the defense-in-depth-principle. To provide a continuous resistance of the barriers, openings in the barriers are equipped with barriers components. The design of barriers in sequence enables adequate counter-actions of the response forces in case of a malevolent act.

The measures according to the Physical Protection concept provide adequate surveillance, monitoring of integrity of barriers, control of access for persons and control of movement for nuclear material.

To enable the separation of areas to be protected and to apply the defense-in-depth principle, four different types of areas are defined:

- **Plant area;** The complete site of the plant is defined as plant area. All buildings and structures necessary for operating the plant are located inside the plant area. The border of the plant area is defined as the inside of the fence
- **Protected area;** Safety relevant buildings are classified as protected areas
- **Vital area;** Areas including vital equipment are defined as vital areas and these are surrounded by protected areas as a rule
- **Restricted area (inside plant, protected or vital area);** If an additional separation inside an area is necessary, a restricted area is arranged

5.2.2. Technical and administrative measures

The Physical Protection measures are divided in following disciplines:

- administrative measures
- mechanical measures
- electrical measures

Administrative measures are the basis for the design of all technical and electrical measures taken into account for the plant design. Well equipped guard personnel will protect the plant permanently and operate the Physical Protection Systems at all times. In case of an attack or unlawful action the police and the governmental authorities will be notified immediately. The mechanical barriers provide sufficient resistance against unauthorized entry and ensure penetration delay.

The barrier components (as mechanical measures) in combination with the electrical Physical Protection System enable the surveillance and monitoring for the integrity of barrier components and the control of access to the specific areas.

5.2.3. Design basis threat to be considered

The design basis threat defined by the Finnish domestic licensing authority (STUK) is taken into account in the KERENA™ design.

5.3. Compliance with guidelines

The objective of the design of Physical Protection for KERENA™ is to comply with guidelines provided by IAEA and STUK.

Description of turbine-generator systems

6.1. Turbine generator plant

The turbine is connected to the RPV by three main steam lines. The bypass station that is installed in parallel to the turbine enables 60% of the steam produced inside the reactor to be dumped directly to the condenser. The turbine generator set consists of a single-shaft saturated-steam turbine coupled directly to a three-phase AC synchronous generator. The 1500-rpm turbine is comprised of one high-pressure (HP) and three low-pressure (LP) turbine sections. Both the generator stator and rotor are hydrogen-cooled. The main steam from the reactor is admitted to the HP turbine section via combined stop and control valves.

After undergoing partial expansion in the HP turbine section, the steam passes through a moisture separator with reheater to the three double-flow LP sections of the turbine. The steam expands in the LP sections through several stages of blading until it reaches condenser pressure.

6.2. Condensate and feedwater systems

The condensate collected in the hotwells of the three condensers is discharged into a common header supplying the main condensate pumps. The condensate passes through a demineralizing system before being heated to final feedwater temperature in feedwater heaters. The feedwater is fed to the reactor via two feedwater lines by variable-speed feedwater pumps.

6.3. Auxiliary systems

The condensate demineralizing system is situated between the two main condensate pumps and the LP feedwater heaters and is installed in the reactor auxiliary building.

The main condensate is passed through the condensate demineralizing system after leaving the turbine condensers. In this system even very small quantities of salts, which may have entered the water via tiny leaks in the turbine condenser, are removed in addition to corrosion products from the steam, condensate and feedwater cycle. The condensate demineralizing system is comprised of five filters arranged in a parallel configuration. Each filter tank is housed in a compartment providing shielding.

Electrical and I&C systems

7.1. Normal power supply systems

The auxiliary power supply system and the offsite power system connection correspond to today's well-proven technology.

The generator feeds power into the main offsite power system via the generator transformer and the main offsite power system connection. The auxiliary power is tapped off between the generator circuit breaker and the offsite power system breaker and fed to the auxiliary power supply system via two three-winding auxiliary power transformers with no-load tap changers. In case of simultaneous loss of the main offsite power system connection and the main generator availability an independent stand-by grid connection consisting of an auxiliary stand-by power transformer and a standby offsite power system connection can be used to supply the auxiliary power for plant shut-down and heat removal.

In view of the different power levels of the various loads connected to the plant's auxiliary power supply system, five voltage levels are provided. For reasons of maintaining voltage stability, only electrical loads with ratings of < 1 MW, such as the emergency power supply train, are connected to the 6-kV busbar. Electrical loads having higher ratings are connected to the 10-kV busbar of each train.

One 690-V emergency power busbar per train is supplied from the 6-kV busbar of the auxiliary power supply system via low voltage transformers for medium sized consumers and one 400-V emergency power busbar per train is supplied for small consumers.

7.2. Safety-related systems

All electrical loads which must remain in operation or must be started up in the event of loss of normal power are connected to the emergency power supply system.

In the event of loss of normal power, an emergency diesel generator takes over independent power supply to all connected electrical loads. Electrical loads for which a period without power is allowable during startup of the emergency diesel generator are connected to the three-phase AC distribution boards of the emergency power supply system.

Electrical loads which, upon loss of normal power, must remain in operation without interruption or must be immediately started up are connected to the uninterruptible power supply (UPS). These loads are supplied with power either directly from the 220-V DC system or indirectly via the downcircuit inverters and the connected 400-V distribution board, or directly from distributed UPS equipment.

In each power supply system train there are two 220-V DC systems (DC subtrain) installed. Each 220-V DC system is fed with power via two redundant rectifiers from the 690-V emergency power distribution board of their respective train. Chargers exist that have sufficient capacity to supply the trickle charge needed to keep the batteries fully charged, the power required by the loads that are connected to only one power supply DC subtrain, and also the power required by the loads powered from diode-decoupled power supplies in both their own and the other DC subtrain.

The batteries are used to supply power during emergency diesel startup following loss of normal power and also to supply the required power in the event of failure of the battery chargers. They are operated in the trickle-charging mode. The batteries are designed such that they can continue to supply the DC loads without interruption from the moment the auxiliary power supply is lost until the load is picked up by the emergency diesel generators and the chargers are reconnected. If the chargers should not be available, the batteries can continue to supply the power requirements of the connected loads for at least two hours.

The 400/230-V inverters are used for providing an uninterruptible power supply to three-phase and single-phase AC loads. They are each supplied from the 220-V DC busbar of their respective system.

Upon failure of an inverter, its downcircuit 400-V distribution board continues to be supplied with power without any interruption via an electronic transfer switch from the 400-V emergency power distribution board of the same train.

The I&C systems are supplied with power at a constant voltage of ± 24 V by the 220-V DC systems via DC/DC converters and inverters via AC/DC converters. The power is supplied from two diode-decoupled power supplies: from a 220-V DC system belonging to the equipment's own DC subtrain and from a 220-V DC system in the second power supply system DC subtrain.

Power is supplied to the monitoring systems and computers at the master control console in the main control room and in the remote shutdown station via inverters or UPS equipment.

7.3. Design concept, including control room

The digital computer based I&C concept planned for the KERENA™ reactor is made up of the following subsystems:

- Operational I&C system:
- Safety I&C system,

I&C encompasses all systems required for process control during normal operation (i.e. during power operation and in the shutdown condition), such as:

- **level 0:** process interface - consists of instrumentation comprising sensors, transducers and data acquisition, control rods, switchgears and actuators.

- **level 1:** system automation - consists of data acquisition, process automation, monitoring and actuation components implemented in the operational system and the safety systems

- **level 2:** unit supervision and control - consists of data processing functions related to human machine interface (HMI) for process control and monitoring implemented in the operational system, process information and control system (PICS) and the safety system, safety information and control system (SICS).

- **level 3:** site management - The systems of this level are not in the scope of supply. Level 3 systems can get information via level 0-2 I&C.

7.3.1 Main control room (MCR)

In this section the function and design of the HMI equipment for process supervision and control are dealt with. The MCR is protected against external hazards. In all plant conditions (except unavailability of MCR) the process of the plant is supervised and controlled in the MCR.

For this task the MCR is equipped with:

- screen-based workplaces consiting of PICS screens in the process control area and in the commissioning/auxiliary area,
- a screen-based workplace (normally only for information) for the shift leader with PICS screens,
- Plant Overview Panel (POP) consisting of large PICS screens that provide an overview of the status and main parameters of the plant and
- the safety control area with HMI equipment of SICS.
- Additionally, the MCR contains a fire alarm board, screens of the video surveillance equipment, and communication terminals available at all operator work places according to their needs.

7.3.2 Process Information and Control System (PICS)

The main task of PICS is to enable the operators to monitor and control the plant. PICS has access to the information of all level 1 systems and presents the information to the operating crew on the following HMI equipment:

- screens for monitoring and control at the operator working places in the MCR,
- screens (normally only display) at the shift leader working place,
- large screens or video projection for the plant overview in the MCR,
- screens for monitoring and control in the RSS,
- screens (only display) in the technical support center (TSC)
- screens for local monitoring and control of Waste Treatment and Reactor Water Cleanup systems
- printers, recorders.

7.3.3 Safety Information and Control System (SICS)

SICS is the safety classified HMI in hardwired technology. It includes hardwired desk tiles for manual control and indication and a limited number of qualified screen displays for monitoring.

The hardwired technology provides means to perform Safety Class 3 and seismic resistant Safety Class 4 control and information functions needed to bring and maintain the plant to safe state in case of design basis contition (DBC) and design extension condition (DEC) events.

The qualified display system (QDS) shall be used for post accident monitoring functions. The process signals for this task are acquired either by SC2 and SC3 classified I&C systems, such as PS and RSCL, or are acquired separately by signal acquisition units of the SICS.

The layout of SICS shall be designed to support operation for the required tasks.

The operators and the shift leader use SICS:

- in case of unavailability of PICS, to bring into or to maintain the plant in the controlled state;

- at DBC 2-4 events and unavailability of PICS to:

monitor the safety functions of the plant, especially the protection system and post accident monitoring system functions,
initiate the manual post accident functions (if any), necessary to reach controlled state,
initiate the manual post accident I&C functions necessary to transfer the plant from the controlled to the safe state,
monitor and control the support systems of safety systems needed for post accident control

7.3.4 Remote Shutdown station (RSS)

The RSS is used to bring toand maintain the power plant in the safe shutdown state in the event of loss of the main control room. The MCR and the RSS are designed and situated so as to preclude a simultaneous loss of both areas.

Process control can be switched over from the MCR to the RSS and back again, as required. However, individual power plant processes can only be controlled from one of these locations at a time.

For process supervision and control the RSS is equipped with:

- a SICS panel in a similar design and layout philosophy as in the Main Control Room, providing displays of the Post Accident Monitoring System. The SICS contains key switches generating commands to PICS to block all control commands coming from the PICS equipment in the MCR. Technical and administrative precautions prevent spurious or not authorised actuation of this function.
- PICS HMI consisting of operator workplaces with screens (same type as in the main control room) to monitor the plant, and providing access to the operation manual.
- Operator workplaces with PICS screens (same type as in the main control room), from which the operators transfer the plant to the safe shutdown state and monitor the plant.

The building containing the RSS is equipped with an independent ventilation system and a secured electrical power supply. All I&C equipment and support systems that are needed for plant operation from the RSS are separated from the MCR area such, that an internal hazard (like fire) cannot disable both MCR and RSS at the same time.

7.3.5 Technical support center (TSC)

The TSC is a room used by the technical support team in case of an accident to accommodate additional staff analyzing the plant conditions and supporting the post accident management.

The TSC is equipped with PICS workstations that have access to all process information, but the process control functions are blocked. Communication means are provided here.

The TSC is located close to the MCR and can also be used during normal operation for meetings and as storage of paper based documentation.

7.3.6 Local control stations

Local control stations are provided for tasks that require close proximity to plant processes. These control stations are only used when local control is necessary. Examples are the emergency diesels, water treatment or sampling system.

Local control stations will be installed, if one of the following conditions is fulfilled:

- As a result of its safety-related functions, it shall be controlled independently of the MCR or the RSS
- Operating control requires a direct link between personnel and process, for example visual or audible contacts

7.4. Reactor protection and other safety systems

The task of the safety I&C systems is to process and monitor key process variables important to reactor safety and environmental protection in order to detect accident conditions and, as a supplement to passive switching operations, to automatically initiate safety functions for maintaining reactor conditions within safe limits. Safety I&C initiates no actions during normal plant operation but takes priority over all operational I&C system functions on demand.

The computer-based process information system is a global information source. Intelligent information processing and reduction enable it to display process conditions and process sequences with a high information content for safety-related and operational tasks. The safety-related alarm and information system first and foremost informs the operating personnel about the status and condition of plant safety equipment. The various I&C subsystems are connected via redundant plant bus in such a way that I&C functions related to autonomous support systems, are organised in autonomous subsystems with provisions against influence from other systems (e.g. functional and electrical isolation, local control stations).

So it can be assured that safety-related systems are separated functional and physical from the control system and other automation systems with lower demands on safety

The safety systems of the KERENA™ consist of both active and passive safety systems. As the passive safety systems alone are capable of controlling most postulated accidents during power operation, the safety I&C equipment can be reduced compared to existing plants. This lean configuration is maintained throughout all I&C, process and power supply systems. The process variables to be monitored are recorded in each train by means of two measuring transducers. Further processing of measuring signals, limit value generation, formation and selection of actuation signals, and logic gating to generate trip signals are all performed by means of a digital system. The trip signals directly actuate a process component or component group.

The provision of 12 passive pressure pulse transmitters (PPPTs) represents a new design feature of the KERENA™ reactor. The function of the PPPTs is to automatically initiate switching operations without any external source of power in the event that the water level in the reactor vessel drops below or exceeds predefined limits. In the case of accident sequences that do not involve an immediate drop in reactor water level but a large rise in pressure, switching operations can be initiated automatically by a PPPT without any external power in response to violation of the pressure limit.

Spent fuel and waste management

An important design objective of the KERENATM reactor was to ensure reduced volumes of liquid waste and concentrates, achieved through for example, the choice of materials for piping and components.

8.1. Solid waste

Reduction in the volume of solid radioactive waste to lessen the unit's impact on the environment was one of the objectives adapted at the design stage.

For optimal treatment, solid radioactive waste in collected separately in groups according to selected criteria based on further treatment, handling, interim storage and final disposal requirements. Depending on the waste type, different equipment is available for waste treatment to prepare it for interim or final storage, such as the super compactor, universally applicable equipment for treating combustible and compressible waste.

Used fuel is removed for either reprocessing or storage, and residual waste created is packaged to ensure that radioactive matter is confined for example in glass.

8.2. Liquid Waste Storage and Processing

Radioactive liquid waste (wastewater) is divided into different categories and collected in separate receiving tanks according to the level of activity, chemical constituents and origin. After separation, it is treated by the most appropriate process: filter systems, evaporator unit or a centrifuge unit.

8.3. Treatment of Radioactive Concentrates

Radioactive concentrates arising are divided into different categories, and are separately collected and held in interim storage tanks according to the level of activity, chemical constituents and origin. The concentrates are treated by the most appropriate processes; such as filter or in-drum drying and may then be stored on site temporarily, before transferred to long-term storage facilities.

8.4. Gaseous Waste Processing

The gaseous waste processing system further limits the potential impact of the plant on the environment by reducing the radioactivity in the off-gas significantly below environmental standards.

The gaseous waste processing system consists of the steam jet air ejectors, the power recombiner units, and the charcoal delay absorbers including a drying unit. The excellent operating experience of these gas waste treatment system technologies, which have been used in many previous BWR plants, leads to a very high system efficiency and availability.

Plant layout

9.1. Buildings and structures, including plot plan

The systems and components are arranged inside the various plant buildings and structures (Figure 4) in clearly delineated structural complexes, thereby enabling the buildings to be constructed in parallel. The reactor building and the turbine building form the central complex of the plant. Other buildings include the switchgear building, the reactor auxiliary building, the reactor supporting systems building, the emergency control room building, the circulating water pump building, the service water pump building and the emergency diesel generator building, and the complex with the second service water pump building and emergency diesel generator building.

In the arrangement of the buildings, a distinction is made between site-specific buildings and structures such as the circulating/cooling water supply systems buildings, and non-site-specific buildings such as the following:

- Reactor building, including containment,
- Turbine building,
- Reactor auxiliary building,
- Reactor supporting systems building,
- Vent stack,
- Emergency diesel generator buildings,
- Service water pump buildings
- Emergency control room building.

Piping and cables between the buildings are either buried underground or routed in ductwork.

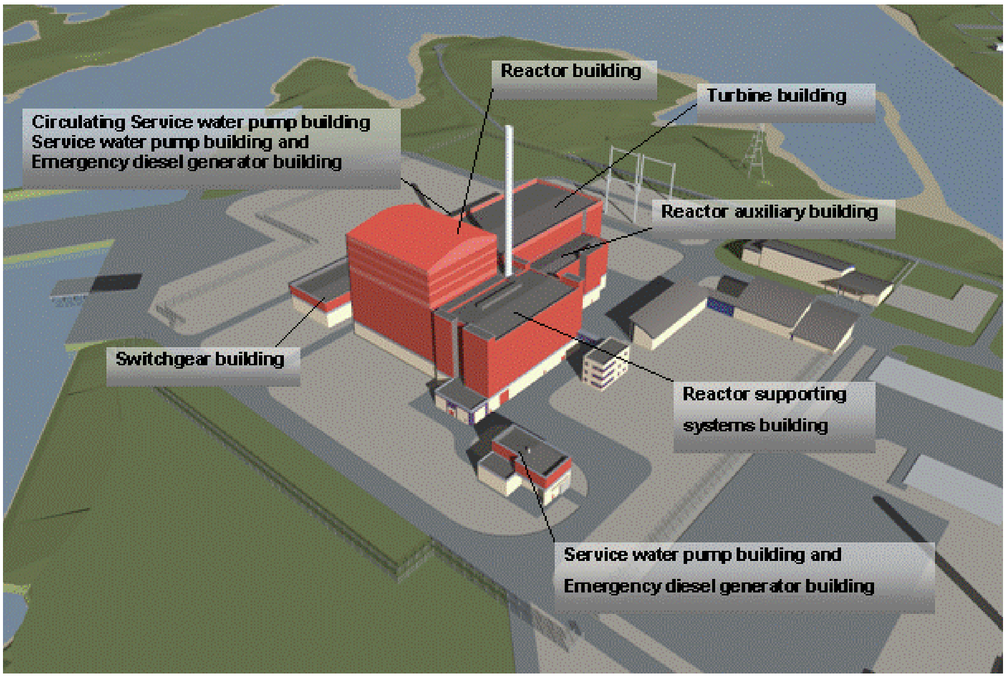

Figure 4: KERENA™ – Typical site layout

9.2. Reactor building

The reactor building (see Figure 5) houses the containment and the safety-related mechanical components, the safety-related electrical and I&C equipment, and the required power supply (batteries) and protection systems. It provides protection against natural and external man-made hazards (including aircraft crash) and serves as a confinement barrier for radioactivity in the event of accidents.

The structural concept is divided into three parts, as follows:

- Outer shell with penetration protection;
- Inner structure, which is largely decoupled from the outer shell
- Containment.

Figure 5: KERENA™ - Reactor building; longitudinal section B-B

9.3. Containment

The primary function of the containment (see Figure 6) is to protect the environment against any release of radioactive materials and against direct radiation under all possible accident conditions.

A cylindrical containment made of steel-reinforced concrete equipped with an inner steel liner and a pressure suppression system has been selected. In keeping with its pressure-suppression-type design the containment is divided into a drywell and a pressure suppression chamber (wetwell).

The containment is also designed to accommodate the pressure buildup due to the hydrogen produced by a 100% zirconium-water reaction, i.e. involving the entire zirconium inventory present in the core, in the event of a core melt accident.

9.3.1 Drywell

In addition to the RPV and the three main steam lines and two feedwater lines, the following components are also located in the drywell: four large hydraulically interconnected core flooding pools, the emergency condensers and containment cooling condensers for passive heat removal, the flooding lines for passive flooding of the RPV, and the passive pressure pulse transmitters for activating safety functions without any need for I&C signals. In addition, the drywell is equipped with two full-capacity recirculation air cooling systems. The HP section of the reactor water cleanup system (HP cooler and pressure-reducing station) as well as the lines of the RHR system are also situated inside the drywell. Due to the shorter control rod drives, the RPV/containment is positioned lower down in the reactor building.

The entire containment is inerted with nitrogen during normal operation. This not only reliably prevents any hydrogen-oxygen reactions in the event of a core melt accident, but also provides fire protection under normal plant operating conditions.

The RHR pumps and heat exchangers are installed in separate compartments located underneath the pressure suppression chamber that are not inerted and are accessible from the outside at all times for maintenance and repairs.

One of the key differences between the containment of a standard BWR plant and that of the KERENA™ reactor lies in the latter's ability to store decay heat inside the containment (due to the larger water inventory) over a longer period of time. As a result it is not necessary for operating personnel to actively intervene within 72 hours after onset of an accident.

7.3.2 Pressure suppression chamber

The pressure suppression chamber performs the following tasks:

- Serves as a heat sink in the event of an accident,
- Provides water for active core cooling via the RHR system.

As part of the pressure suppression system, the pressure suppression chamber is located between the outer and inner containment cylinders beneath the core flooding pools and is to 40% filled with water. The pressure suppression chamber is connected to the drywell via vent pipes embedded in the concrete of the inner cylinder. In addition, the pressure suppression chamber and core flooding pools are connected to each other via submerged water overflow and hydrogen overflow pipes. Connections between the drywell and the air space of the pressure suppression chamber used in existing BWR plants, such as pressure-equalizing valves, have been replaced by passively operating water filled siphons.

9.3.3 Core flooding pools

The interconnected core flooding pools act as a heat sink for the emergency condensers and the safety-relief valve system. In addition, owing to the pools' elevation, the water in the core flooding pools is used for passive flooding of the reactor core following RPV depressurization in the event of a LOCA. For this function, check valves open the core flooding lines automatically. Passive core flooding serves as a diverse measure of providing RPV coolant supplementing the active core cooling system.

In the event of a core melt accident, core flooding pool water is used to cool the RPV from the outside.

The four connected core flooding pools are located above the pressure suppression chamber and are approximately two-thirds filled with water. They are physically separated from each other by equipment compartments containing mechanical components, piping and ventilation equipment. Each pool houses an emergency condenser, a containment cooling condenser (above the water surface), a core flooding line connection, and two SRV discharge pipes with steam quenchers.

In addition, one drywell flooding line for cooling of the RPV exterior leads down to the bottom of the drywell.

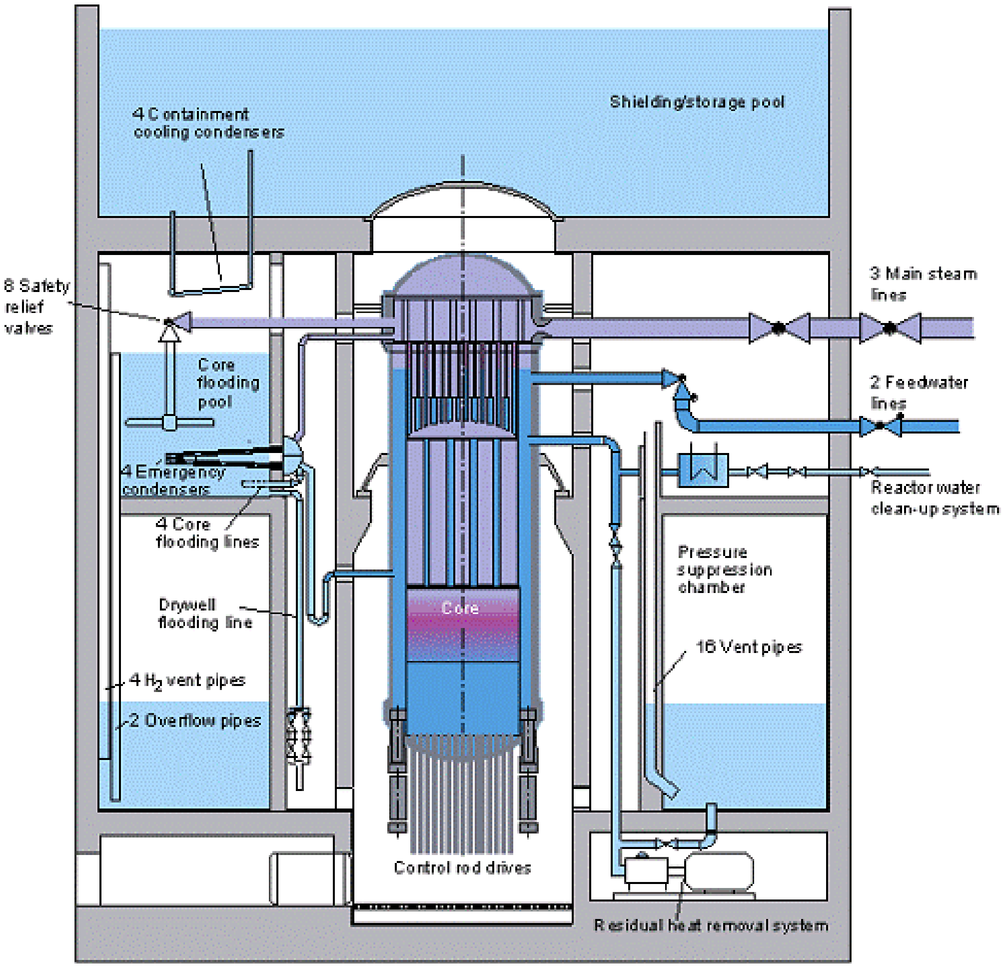

Figure 6: KERENA™ - Containment

9.4. Turbine building

The turbine building mainly contains the systems and components of the steam, condensate and feedwater cycle, such as the condensate and feedwater pumps and feedwater heaters as well as the turbine and generator.

The turbine building is part of the controlled access area of the plant.

9.5. Other buildings

9.5.1 Reactor auxiliary building

The reactor auxiliary building contains systems and components used for processing and storage of liquid radioactive waste, including the evaporator system.

The liquid waste processing and storage system is arranged such as to ensure short piping connections to the system and equipment areas in the turbine building and reactor building.

9.5.2 Reactor supporting systems building

The reactor supporting systems building contains the workshops and parts of the waste processing and storage system, as well as the central entrance to the controlled access area. This building houses components belonging to the following systems:

- Main control room;
- Intake and exhaust air system;
- Sanitary facilities, in particular the changing rooms and washroom facilities required at the entrance to the controlled access area;
- Laboratory;
- Hot workshop and decontamination facilities;
- Reserved space for mobile concentrates treatment unit with drum store for low-level waste;
- Non-safety-related switchgear.

Plant performance

The overall objective was to develop an economically competitive plant while achieving higher levels of safety than the existing fleet of BWR plants and reducing the risks associated with licensing and construction of a new nuclear power plant.

10.1 Economic competitiveness

By designing the plant to rely on passive and active systems for safety functions a significant reduction in total plant cost has been realized. Passive systems also require less support systems than active systems.

Savings can also be achieved by combining system functions, resulting in fewer systems. The KERENA™ reactor design has eliminated some of the previously standard BWR systems by incorporating their functions into other systems, thereby reducing the total number of systems.

10.2 High level of safety

The KERENA™ design achieves very high levels of safety while reducing the complexity of the safety systems through the use of "passive" safety equipment. As a result of this approach, the following attributes were realized:

- Clear and simple systems engineering
- Increased safety margins
- More robust reaction to off-normal conditions
- Increased grace periods (up to several days) after the onset of accident conditions before intervention by operating personnel is required
- Effect of human error on reactor safety is minimized by used of the passive actuation systems
- Much lower probabilities of occurrence of accidents leading to core melt
- The effects of a core melt accident are limited to the plant itself.

10.3 Reduction of risks associated with licensing and construction

A European utility group successfully assessed compliance of the KERENA plant with the European Utility Requirements. The main assessors were EDF (France), TVO (Finland), and the German utilities.
In the frame of an application for a decision in principle the Finnish authority STUK assessed the KERENA™ reactor as licensable in Finland.

The construction time for the KERENA™ reactor is reduced as a direct result of the simplification of systems and the incorporation of passive equipment. These two aspects of the design have resulted in fewer total components and have significantly reduced the number of safety-classified components.

Development status of technologies relevant to the NPP

In the past all innovative components or systems of KERENA™ have been tested. Components like the passive pressure pulse transmitters have been tested in full scale while others like the emergency condensers have been tested in a reduced scale setup. The goal of the current testing program is to complete the full scale testing program.

The key elements of the passive safety concept: The emergency condenser (EC), the containment cooling condenser (CCC), the passive core flooding system (PCF) and the passive pressure pulse transmitter (PPPT) will be tested at the test facility INKA (Integral test facility Karlstein) in Karlstein Germany. The INKA program is divided in two mayor parts. The EC, the CCC and the PCF will be tested in full scale in order to determine the operational characteristic of the components. In the second step, transients and LOCA (Loss Of Coolant Accident) scenarios will be simulated experimentally in order to show the interaction between the components and to demonstrate the ability of the passive systems to handle all anticipated accident scenarios without the intervention of active systems. For these integral tests the KERENA™ Passive Pressure Pulse Transmitter (PPPT) will be included.

The INKA test facility is designed to perform the single component tests as well as the integral tests. The volume scaling was chosen as 1:24.

The vertical distances between components, water levels, floors and ceiling of the KERENA™ containment that are important for the function and the capacity of the tested components will be simulated equally to the real plant.

Figure 7 shows a comparison of the test facility and the KERENA™ containment. The containment compartments flooding pools (green), drywell (red) and pressure suppression pool are simulated at INKA by the flooding pool vessel (FPV), the drywell vessel (DW) and the pressure suppression pool vessel (PSPV).

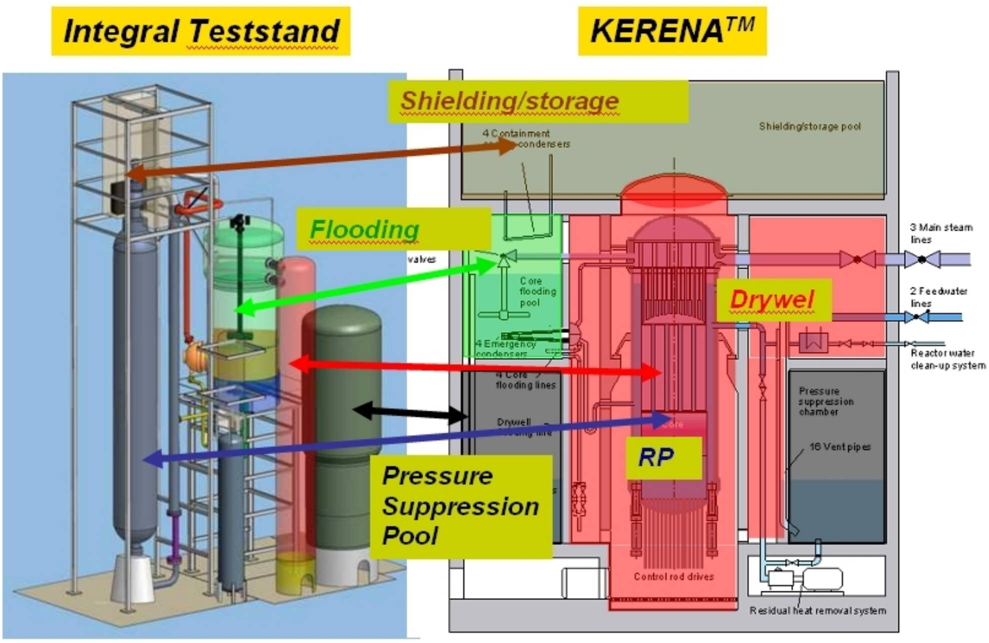

Figure 7: Comparison between the KERENA™ containment and the INKA test facility

In support of the testing program two further test facilities will be built: one for the full scale testing of the KERENA™ scram system and one for the passive outflow reducer.

Deployment status and planned schedule

In mid 2008 E.ON and AREVA NP signed a contract for the final basic design on KERENA™. Within this contract for the final basic design, the partner AREVA NP and the German utility E.ON support the project according to their roles as plant vendor and operator.

The objectives of this partnership are

- Preparation of documents for a construction permit
- Preparation of a 3D-Model for all buildings of the NI
- Review and customization of the design to ensure minimization of risks in case of an order

In parallel an experimental validation program is carried out for the key elements of the passive safety concept. All new passive components will be tested in full scale before the end of 2010.

The planned schedule is to prepare the documentation for a construction license application in 2011.

References

1. International Atomic Energy Agency, Status of advanced light water reactor designs, IAEA-TECDOC-1391, Vienna (2004)
2. AREVA NP, KERENATM - The 1250MWe Boiling Water Reactor, 3 N Symposium Geneva March 17 th /18th , 2010

Technical data

General plant data

Reactor thermal output	3370 MWth
Power plant output, gross	1290 MWe
Power plant output, net	1250 MWe
Power plant efficiency, net	37 %
Mode of operation	Baseload and Load follow
Plant design life	60 Years
Plant availability target >	92 %
Thermodynamic cycle	Rankine
Type of cycle	Direct

Safety goals

Core damage frequency <	10E-7 /Reactor-Year
Large early release frequency <	30E-8 /Reactor-Year
Occupational radiation exposure <	0.5 Person-Sv/RY
Operator Action Time	72 Hours

Nuclear steam supply system

Steam flow rate at nominal conditions	1850 Kg/s
Steam pressure	7.5 MPa(a)
Steam temperature	290 °C
Feedwater flow rate at nominal conditions	1840 Kg/s
Feedwater temperature	220 °C

Reactor coolant system

Primary coolant flow rate	13200 Kg/s
Reactor operating pressure	7.5 MPa(a)
Core coolant inlet temperature	282 °C
Core coolant outlet temperature	290 °C
Mean temperature rise across core	8 °C

Reactor core

Active core height	3.0 m
Equivalent core diameter	5.553 m
Average linear heat rate	12.7 KW/m
Average fuel power density	24.7 KW/KgU
Average core power density	51 MW/m^3
Fuel material	UO2 and MOX
Outer diameter of fuel rods	10.05 mm
Rod array of a fuel assembly	12x12-16Q
Number of fuel assemblies	664
Fuel cycle length	24 Months
Average discharge burnup of fuel	60 MWd/Kg
Control rod absorber material	B4C

Reactor pressure vessel

Inner diameter of cylindrical shell	7120 mm
Wall thickness of cylindrical shell	191 mm
Design pressure	8.8 MPa(a)

Design temperature	300 °C
Total height, inside	23450 mm
Transport weight	995 t

Reactor coolant pump (Primary circulation System)

Pump Type	Vertical axial
Number of pumps	8
Pump speed	1661 rpm
Head at rated conditions	22.5 m
Flow at rated conditions	2.3 m^3/s

Primary containment

Overall form (spherical/cylindrical)	Cylindrical
Dimensions - diameter	33 m
Dimensions - height	36.5 m
Design pressure	0.35 MPa
Design temperature	140 °C
Design leakage rate	0.5 Volume % /day

Turbine

Number of turbine sections per unit (e.g. HP/MP/LP)	1HP / 3LP
Turbine speed	1500 rpm
HP turbine inlet pressure	7.3 MPa(a)
HP turbine inlet temperature	289 °C

Generator

Rated power	1445 MVA
Active power	1300 MW
Voltage	27 kV
Frequency	50 Hz

Condenser

Condenser pressure	4 kPa

Feedwater pumps

Flow at rated conditions	1840 m^3/s