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IRIS

SPES3-IRIS Facility

Westinghouse

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WCAP-16842-NP

IRIS
(INTERNATIONAL REACTOR INNOVATIVE & SECURE)
SPES3-IRIS Facility

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August 2007

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ABSTRACT

The purpose of this topical is to provide details of the test matrix and test facility design description for the integral tests planned for the International Reactor Innovative and Secure (IRIS) nuclear power plant (Reference 1). IRIS is an advanced, integral, light-water cooled reactor of medium generating capacity (335 MWe), geared at near term deployment (2012-2015). IRIS is an innovative design that features an integral reactor vessel that contains all the reactor coolant system components, including the steam generators, coolant pumps, pressurizer and heaters, and control rod drive mechanisms, in addition to the typical core and control rods, and reactor internals. The details of the test matrix and the integral SPES3-IRIS facility design are provided in Appendices 1 and 2 respectively.

These integral effects tests 1) will examine the integrated performance of components and/or systems which are also required for design certification and 2) will provide thermal-hydraulic data for computer code validation and/or will ensure that new components and system functions important to plant safety are demonstrated.

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1.0 INTRODUCTION AND SUMMARY

Westinghouse Electric Company, in conjunction with a large consortium of engineering, academic, and utility organizations is developing an advanced light water reactor design known as IRIS (International Reactor Innovative and Secure). The IRIS is a new design and, as such, it must conform to the requirements of 10 CFR 50, Part 52, which states, "Certification will be granted only if the performance of each safety feature of the design has been demonstrated through either analysis or the appropriate test programs, experience, or a combination thereof; interdependent effects among the safety features of the design have been found acceptable by analysis, appropriate test programs, experience or a combination thereof; and sufficient data exist on the safety features of the design to assess the analytical tools for safety analysis over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium conditions." To comply with the requirements of 10 CFR 50, Part 52, the overall IRIS test plan (Reference 2) will provide the necessary data for the development, assessment, and verification of the computer models used for safety analyses.

As part of this overall test plan the Italian Società Informazioni Esperienze Termoidrauliche (SIET) will perform integral effects tests utilizing the Simulatore Per Esperienze di Sicurezza (SPES)3 facility that examine the integrated performance of components and/or systems which are also required for design certification. The details of the test matrix covering IRIS transients including double ended pipe breaks and long term cooling capability are provided in Appendix 1. A detailed description of integral SPES3-IRIS facility design is provided in SEIT report SIET 01 334 RT 07 Rev.0 as Appendix 2. The results of these tests will provide thermal-hydraulic data for computer code validation and/or will ensure that new components and system functions important to plant safety are demonstrated.

2.0 REFERENCES

1) *IRIS Plant Description Document*, WCAP-16062-P and WCAP-16062-NP, Rev. 0, March 2003.
2) *IRIS Test Plan,* WCAP-16392-P and WCAP-16392-NP, Rev. 0, July 2005.

APPENDIX 1.

IRIS SPES3 Integral Test Matrix

IRIS SPES3 Integral Test Matrix

(a, c)

APPENDIX 2

SPES3-IRIS facility design

SIET 01 334 RT 07 Rev.0

Titolo

Status of SPES3-IRIS Facility design

Ente emittente

PAGINA DI GUARDIA

Descrittori

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Sommario

IRIS is an integral modular, medium size PWR, under development by an international consortium with approximately 20 partners led by Westinghouse.

The licensing process required by the U.S. Nuclear Regulatory Commission (NRC) foresees an experimental campaign to verify the behaviour of the new plant and its safety system capabilities to cope with postulated accidents.

To this end an experimental facility, so-called SPES3-IRIS, will be built at SIET laboratories (Piacenza, Italy) simulating, with 1:100 volume scale and 1:1 height scale, the primary, secondary, containment and safety systems typical of the IRIS reactor

This document deals with the basic of SPES3-IRIS facility reference design.

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III. NOMENCLATURE

ADS	Automatic Depressurization System
ASME	American Society of Mechanical Engineers
BAF	Bottom of Active Fuel
CVCS	Chemical Volume Control System
DAS	Data Acquisition System
DC	Downcomer
DP	Differential pressure
DVI	Direct Vessel Injection
EBT	Emergency Boration Tank
EHRS	Emergency Heat Removal System
F	Flowrate
FL	Feed Line
FW	Feed Water
IRIS	International Reactor Innovative and Secure
L	Level
LEL	Lower electric limiting
LGMS	Long Term Gravity Make-up System
LOCA	Loss of Coolant Accident
MSLIV	Main Steam Line Isolation Valve
NPP	Nuclear Power Plant
NRHR	Normal Residual Heat Removal
P	Pressure
PSS	Pressure Suppression System
PT	Pressure Tap
PWR	Pressurized Water Reactor
Q	Volumetric flowrate
QT	Quench Tank
RC	Conical Reduction
RCCA	Rod Cluster Control Assembly
R&D	Research and Development
RPV	Reactor Pressure Vessel
RWST	Refuelling Water Storage Tank
S	Steam

SIET	Società Informazioni Esperienze Termoidrauliche
SG	Steam Generator
SGMT	Steam Generatora Make-up Tank
SL	Steam Line
SPES	Simulatore Per Esperienze di Sicurezza
T	Temperature
TAF	Top of Active Fuel
UEL	Upper electric limiting

1. SCOPE

The primary goal of testing on the SPES3-IRIS facility is to demonstrate the vessel to containment coupling as the main safety issue of IRIS plant in mitigating small LOCAs.

The SIET company has large experience in advanced safety testing having provided the experimental results needed to the AP-600 qualification.

As for AP-600, SIET will perform the IRIS tests in the SPES3 facility that will be built as described in this document and will be suitable for both integral and separate effect tests.

This document, in Rev. 0, describes the basic of SPES3-IRIS facility design at June 2007. Further details will be reported in the as-built version that will be issued after the facility mounting and build-up.

2. INTRODUCTION

The International Reactor Innovative and Secure (IRIS) is an integral modular, medium size PWR, under development by an international consortium with approximately 20 partners led by Westinghouse. IRIS is a pressurised water reactor with an integral coolant system layout where the vessel houses the major primary coolant system components: pumps, steam generators, pressurizer and in addition to the neutron reflector, nuclear fuel and control rods, also the control rod drive mechanism.

The licensing process required by the U.S. Nuclear Regulatory Commission (NRC) foresees a series of experimental tests on properly built facilities suitable to verify the behaviour of the new plant and its safety system capabilities to cope with postulated accidents.

The SPES3-IRIS integral test facility will be built at SIET laboratories simulating, with 1:100 volume scale and 1:1 height scale, the primary, secondary, containment and safety systems typical of the IRIS reactor.

It will be suitable to perform both integral and separate effect tests and will investigate the thermal hydraulic interaction among the various systems.

3. DESIGN CRITERIA

3.1 General design criteria

The SPES3-IRIS is an integral test facility modelling the IRIS reactor [1], in particular:

- the primary system including the RPV with power channel, circulation pump, pressurizer, EBT and ADS;
- the secondary systems up to the MSLIV, including three SGs simulating eight, with helical coils (loop A and B simulate two SGs each, loop C simulates four);
- the containment system including the dry well, the quench tank, the reactor cavity, the PSS, the LGMS;
- the safety system including the EHRS located in the RWST;
- the non safety systems including the Start-up FW.

The overall volume scaling factor is 1:100 and the height scaling factor is 1:1.

The process fluid is water.

The maximum power is 6.5 MW:

The main parameters preserved by scaling are:

- the fluid thermodynamic conditions (temperature, pressure, enthalpy);
- vertical elevation;
- power to volume ratio **[** **]**(a,c);
- power to flow ratio;
- transit time of fluid;
- heat flux.

Additional scaling criteria are applied to design selected components in order to better reproduce specific phenomena occurring in the IRIS plant during an accident.

3.2 Specific design criteria

3.2.1 Reactor pressure vessel

- The vertical elevation of the RPV is preserved;

- The vertical elevation of the RPV connections to the piping is preserved;
- The DC cross flow area is preserved both in the lower DC and at the SG pipe rows narrow sections;
- The riser, SG central columns and annular space are simulated in a unique riser volume;
- The pressurizer height and elevation are simulated;

3.2.2 Power channel

- The vertical power channel vertical elevation is preserved as in the Westinghouse Standard fuel 17x17;
- The bundle geometry (rod pitch and diameter) is preserved;
- The rod number is scaled by **[ ]$^{(a,c)}$**;
- The rod spacer grids are not prototypical, but the core pressure drops is properly scaled by orificing at the bundle outlet;

3.2.3 Fuel bundle box

The fuel bundle box/barrel structure is chosen by **[ ]$^{(a,c)}$** on the thermal mass and on the global heat transfer coefficient.

3.2.4 Reactor coolant pump

- The limited room available inside the RPV does not allow to fit internal pumps, so a single outer pump is foreseen to distribute water to the three SGs.

3.2.5 Pressurizer

- The pressurizer inverted hat shape is reproduced by maintaining the plant elevation and **[ ]$^{(a,c)}$** scaled volume.
- The connection to the riser is performed by one surge hole whose area is scaled to be **[ ]$^{(a,c)}$** than the global plant ADS nozzles area in order not to limit the discharge flow in case of ADS intervention.
- An electrical vertical heater allows to control the pressure during steady state.

3.2.6 Steam Generators

- Four helical coil tube rows simulate the eight IRIS SGs. **[ ]$^{(a,c)}$**.
- A direct scaling of SG number of tubes would lead to have in SPES3 facility four rows with **[ ]$^{(a,c)}$**.
- Evaluations on possible thickness reduction and use of **[ ]$^{(a,c)}$**.

3.2.7 Secondary circuit Feed Line and Steam line

- The Feed Line and Steam Line connections to the RPV consist of four **[ ]$^{(a,c)}$** Sch.160 nozzles to allow the SG tubes to exit the RPV. The FL and SL diameter as weel as the line routing must be confirmed once the EHRS design is completed. Loop seals must be avoided along the pipe paths. The same elevation difference between vessel connections and EHRS connections is respected.

3.2.8 EHRS

- The preliminary IRIS plant EHRS design consists of two twin modules of **[ ]$^{(a,c)}$** pipes connected to two horizontal cylindrical collectors. IRIS has four EHRS, the SPES3 facility has three, simulating four, each connected to a secondary loop. The EHRS connected to the third loop simulates two EHRSs perteining to the double loop. The three EHRS are placed in the same RWST.

3.2.9 RWST

- The RWST design is strictly related to the EHRS shape. A square base pool contains the three EHRSs.

3.2.10 EBT

- There are two EBTs. Each EBT has a volume of **[ ]$^{(a,c)}$**.

3.2.11 Containment system

- The containment system is simulated by means of different tanks scaled in volume **[ ]$^{(a,c)}$** and located at the same elevation as in the IRIS plant. The tank shape is suitable to reproduce the same

volume versus height of IRIS plant containment compartments. Piping connects the RPV. Such pipes do **[**
](a,c).

3.2.12 Dry Well

- The dry well is a cylindrical tank which volume is **[** **]**(a,c).

3.2.13 PSS

- There are two PSSs. The PSS volume is **[**
](a,c).

3.2.14 Reactor Cavity and DVI room

- The reactor cavity volume is **[**
](a,c).

3.2.15 LGMS

- There are two LGMSs. Each LGMS volume is **[**
](a,c).

3.2.16 Quench tank

- The QT volume is **[** **]**(a,c).

3.2.17 Containment piping

- The PSS vent lines connect the Dry Well to the PSS ending underwater with a sparger.
- The PSS-LGMS Pressure Balance Lines connect the PSS top to the LGMS top.

- The PSS to DVI line.
- The LGMS to DVI lines.
- The DVI line.

3.2.18 ADS

- Two trains of ADS simulate the three trains of the IRIS plant. Piping leads to a sparger ending into the QT.

3.2.19 Break lines

- Three break locations are foreseen on the primary side: a) lower break at the DVI line; b) upper break at the EBT (CVCS) connection line to the RPV; c) ADS break line. Both split and double ended guillotine breaks (DEG) can be simulated in case of DVI, EBT and ADS line breaks.

  Two break locations are foreseen on the secondary side to simulate the FL and SL DEG breaks inside containment.

3.2.20 Auxiliary systems

- The auxiliary systems provide water to the test facility at the required temperature, pressure and flowrate. A few modifications will be needed to the already existing systems at SIET.
- The Start-up FW is provided by the auxiliary systems at the required pressure, temperature and flowrate.

4. FACILITY DESCRIPTION

The SPES3-IRIS facility will be built at SIET Laboratories in Piacenza, inside the building of the decommissioned Emilia oil fired power plant.

The SPES-3 will be located on the same load-bearing structure where the SPES and SPES-2 facilities had been built in the past. The SPES-2 components will be completely removed. Fig.4.1 through Fig.4.11 show the component location on the load-bearing structure in front, side and plan view.

The facility consists of the primary system, the secondary systems, the containment system and the auxiliary systems. The flow diagrams of the systems are reported in Fig.4.12 through Fig.4.16.

4.1 The primary system

The primary systems consists of a RPV housing the electrically heated fuel rods, the Riser and Downcomer paths, the Pressurizer, the helical coil Steam Generators. An outer circulation pump is foreseen with delivery paths to the single SGs.

4.1.1 RPV

The Reactor Pressure Vessel is shown in Fig.4.17.

It is a cylindrical pressure vessel consisting of three main parts coupled by flanges.

The lower part contains the fuel bundle and related box/shield, the lower downcomer, the fuel bundle support and closure system that allows the rods to exit the RPV bottom.

The intermediate part contains the riser and the upper downcomer with the three SGs. The four helical pipe rows are wrapped around the cylindrical riser. A cylindrical barrel separates the inner row from the intermediate one and another barrel separates the intermediate row from the two outer rows.

The upper part contains the Pressurizer.

The RPV is provided of nozzles for the FL and SL penetration to SGs, for the DVI line connections, for the pump suction and delivery, for the EBT upper line connections, for the ADS. The vertical position of nozzles is established on the basis of the IRIS plant model prepared for Relap5 code simulation and ENSA drawings.

4.1.2 Fuel bundle

The fuel bundle consists of **[** **]**$^{(a,c)}$. The Westinghouse 17 x 17 Standard fuel bundle is simulated from the point of view of rod diameter, pitch and length. The active length of the fuel is **[**
]$^{(a,c)}$. In the reactor, this is the fuel length included between the lower and upper core

plates. The SPES3 fuel bundle extends downwards in order to exit the RPV from the bottom and connect the electrical poles.

A constant axial power profile is provided. The radial profile is uniform with the exception of two hot rods with a peaking factor of 1.6. The cross section of the bundle is shown in Fig.4.18.

The maximum electrical power of 6.5 MW is available for the SPES3 facility power channel.

The rod heating mode is indirect, i.e. an electrical resistance is located inside the cylindrical cladding and electrically insulated from the outer shell by a mineral oxide. Both the electrical connections of the positive and negative poles exit from the rod bottom.

The rods are maintained in their relative positions by **[ ]$^{(a,c)}$** spacer grids located at different elevations along the bundle. The grids are not prototypical and the pressure losses across the core will be adjusted by proper orificing at the core outlet. A spacer grid is shown in Fig.4.19.

4.1.3 Fuel bundle box

The fuel bundle is contained in a box, open at the bottom and top, acting as downcomer barrel and creating the descending and rising flow paths. The rod spacer grids are welded at the inner layer of the box, Fig.4.20.

In order to simulate the IRIS plant core shield thermal inertia and heat transfer, a double layer box with honeycomb wave fillers inside has been adopted, as shown in Fig.4.21. The thermal and mechanical parameters of the box have been verified showing that the thermal mass ratio and the overall thermal conductance ratio between IRIS and SPES 3 satisfy the scaling criteria and that the mechanical structure satisfy the maximum stresses allowable constraints.

The whole assemble fuel bundle and box is inserted into the RPV from the bottom. Guide sleeves center the assembly in the correct position up to the box upper guide in correspondence of the connection flange. Such guide is shaped as the fuel box with a **[ ]$^{(a,c)}$** for insertion, Fig.4.22. The thermal expansion of rods and fuel box is allowed, while the water bypass seems negligible with respect to the total flow.

4.1.4 RPV bottom closure and sealing system

The fuel bundle box is supported by a perforated cylindrical pipe suitable to drive the downcomer flowrate toward the fuel bundle. A support and sealing system closes the RPV bottom preventing leakages through the rod penetrations, Fig.4.23. The sealing system consists of a series of graphite gaskets placed among stainless steel stuffing disks. A closure flange packs the layers and is joined to the RPV by bolts.

4.1.5 RCCAs

The RCCAs are simulated in the SPES3 only from the point of view of occupied volume and pressure losses. They are included in the lower riser and are simulated simply by pipes and grids .

4.1.6 Riser

The SPES3 riser is a cylindrical volume that simulates all together in a single component the IRIS reactor cylindrical riser, SG annular space and the Central columns.

The lower riser contains the RCCAs, while the upper riser is empty.

The vertical cylindrical riser is shown in Fig.4.17, but the RCCAs simulators are not reported in the figure yet. Fig.4.24 shows a detail of riser horizontal cross section with the SG pipe rows position among the barrels.

4.1.6 SGs primary side

The SPES3 inner SG pipe row simulates **[**

]$^{(a,c)}$. The cross sectional dimensions of the SG annuli are chosen in order to give a performance as uniform as possible among the SGs and as close as possible to the performance of the IRIS plant SG. The two outer rows are coiled with equal inclination to allow enough room for instrument penetration, given the heat transfer coefficient is not affected by the relative inclintion.

The SG rows are maintained in both their axial and radial position by **[**

]$^{(a,c)}$, Fig.4.25.

4.1.7 Pressurizer

The IRIS plant inverted hat pressurizer is simulated as shown in Fig.4.17.

The diameter of the single surge hole is Φ = **[**
]$^{(a,c)}$ Sch. 160) and scaling considerations.

A vertical cylindrical electrical heater is inserted from the top with the nominal power of 200 kW suitable to compensate heat losses during the steady state and maintain the specified pressure.

4.1.8 Pump

The IRIS plant pumps are simulated in SPES3 by a single outer pump which provides the required flowrate and head.

In order to be able to regulate or exclude one or more SGs from the operation, the pump delivery is separated toward the three SGs as shown in Fig.4.26. Four **[ ]**$^{(a,c)}$ Sch. 160 nozzles are related to the pump suction and four equal nozzles are related to the pump delivery. Pump suction and delivery are connected to common circular collectors. Between the delivery collector and the RPV nozzles, four separate lines are provided to distribute and measure the flow to the SGs.

Four pump bypasses are provided and located just at the outlet of each nozzle, Fig.4.26. Each bypass line contains a check valve which is closed when the pump is in operation and open when it is stopped.

Two plates with adequate fissures, welded at different elevations under the pump-RPV connections, allow a symmetric distribution of water injected from the pump at the SGs inlet, Fig.4.27, Fig.4.17.

4.1.9 EBT

The SPES3 EBT volume is **[ ]**$^{(a,c)}$. It is a cylindrical vessel with elliptical bottoms as shown in Fig.4.28.

4.2 The secondary system

The secondary system consists of three loops, each connected to one SG, that allow to remove heat generated in the RPV and dissipate it in the SIET condensation and discharge loop. Two loops are **[ ]**$^{(a,c)}$. Each loop simulates the IRIS plant pipes up to the main SL and FL isolation valves, while after such valves, the loops need no longer to be prototypical. Feed Lines and Steam Lines are simulated respecting the elevation differences as in IRIS plant.

4.2.1 SGs secondary side

On the basis of an ASME code case change, the possibility of reducing the IRIS plant SG pipes thickness (2.11 mm) and length (32 m) was investigated and it was found that a **[ ]**$^{(a,c)}$.

Manufacturer information on the possibility to build **[ ]**$^{(a,c)}$.

Notwithstanding the lower thermal conductivity of AISI 316L compared to Inconel 690 TT, the use of AISI 316L is envisaged mostly for **[**

]$^{(a,c)}$.

4.2.2 EHRS

The IRIS EHRS takes advantage of the experience by Ansaldo for the vertical heat exchagers, tested in the past at SIET for SBWR Isolation Condenser applications. The IRIS EHRS consists of two twin vertical modules with **[ ]**$^{(a,c)}$ tubes each and horizontal cylindrical headers. An advantage of the EHRS geometry, with enough water contained in its headers, is to eliminate the need for SGMTs [1].

In the SPES3 facility, the EHRS related to each loop is simulated by components with **[**

]$^{(a,c)}$. The upper and lower collectors are simulated by vertical cylindrical pipes suitable to maintain the correct elevation and the scaled volume, Fig.4.29, Fig.4.30. The pipe pitch is the same as the IRIS plant EHRSs and the three components are placed in the same RWST as close among them as possible, in order to have a sort of bundle effect. This solution allows the exclusion of one or more EHRS from the circuit on the basis of the required tests.

4.2.3 RWST

Only one pool is simulated in SPES3 containing the three EHRS. Its volume is **[**

]$^{(a,c)}$.

The RWST bottom is located 1 m above the SL nozzle centerline.

4.3 The containment system

The SPES3 containment system consists of different tanks simulating separately the IRIS containment compartments, in particular the Dry Well, Quench tank (QT), Pressure Suppression Systems (PSS), Long Term Gravity Make-up Tanks (LGMS) and Reactor Cavity with DVI room. Once defined volume and height of the components, on the basis of IRIS plant configuration, the SPES3 tank shape have been designed to satisfy both the hydraulic and manufacturability constraints.

The ADS system and the DVI line are considered as part of the containment.

4.3.1 Dry Well

The SPES3 Dry Well volume is **[** **]**$^{(a,c)}$. The inner profile of the tank is shown in Fig.4.31.

4.3.2 Quench Tank

The SPES3 QT volume is **[** **]**$^{(a,c)}$. The inner profile of the tank is shown in Fig.4.32.

4.3.3 Pressure Suppression System

The SPES3 PSS volume is **[** **]**$^{(a,c)}$. The inner profile of the tank is shown in Fig.4.33.

4.3.4 LGMS

The SPES3 LGMS volume is **[** **]**$^{(a,c)}$. The inner profile of the tank is shown in Fig.4.34.

4.3.5 Reactor cavity and DVI room

The SPES3 Reactor cavity and DVI room are simulated by a single tank of **[** **]**$^{(a,c)}$. The inner profile of the tank is shown in Fig.4.35.

4.3.6 ADS system

[**]**$^{(a,c)}$ Sch.160 nozzles on the IRIS plant RPV are the starting points of the **[** **]**$^{(a,c)}$ trains of the ADS system. Each of them in connected to one 4 inch Sch.160 line, **[** **]**$^{(a,c)}$ safety valve .

In SPES3 facility a single ADS train simulates **[** **]**$^{(a,c)}$.

The flowsheet indicates the pipe flow, Fig.4.12.

The ADS line ends into the Dry Well Quench Tank with a sparger. The sparger geometry is based on the **[** **]**$^{(a,c)}$, with a number of holes suitable for IRIS.

4.3.7 DVI

The DVI line allows the injection of water into the RPV from the EBT, from the cavity, from the PSS and LGMS. Two symmetric DVI lines are foreseen in SPES3, each collecting water from a single train of tanks and from cavity and injecting into the RPV in two points at different elevations. A further penetration can inject water into the lower downcomer, if required. A sketch of connections is shown in Fig.4.36.

The SPES3 DVI line diameter is **[** **]**$^{(a,c)}$.

4.3.8 PSS vent lines

Each PSS vent lines connects the Dry Well to the PSS, ending under water with a sparger. The flowsheet indicates the pipe flow, Fig.4.12.

4.3.9 PSS-LGMS balance lines

Each PSS to LGMS balance line connects the top of the PSS to the top of the LGMS. The flowsheet indicates the pipe flow, Fig.4.12.

4.3.10 PSS to DVI lines

Each PSS to DVI line connects the water space of the PSS to the DVI line. The flowsheet indicates the pipe flow, Fig.4.12.

4.3.11 LGMS to DVI lines

Each LGMS to DVI line connects the LGMS bottom to the DVI. The flowsheet indicates the pipe flow, Fig.4.12.

4.4 Break lines

Proper break lines connect the break points to the containment tanks, Fig.4.12, Fig.4.14. The piping configuration is suitable to simulate both split and double ended guillotine breaks (DEG) by means of a proper valve configuration. In general, the break elevation and the piping connections to containment tanks are at the same elevation as if break flow were directly discharged into the containment.

4.4.1 Lower break line

The lower break line is the DVI break at the RPV injection, before the fork to the two injection points.

Small breaks are foreseen and the break size is defined in the test matrix. Proper break orifices set the desired flow.

The lower break discharges into the Reactor cavity DVI room. Both split and double-ended breaks are simulated with the valve disposition as shown in Fig.4.37.

4.4.2 Upper break line

The upper break is the EBT – RPV upper connection line break.

Small breaks are foreseen and the break size is defined in the test matrix. Proper break orifices set the desired flow.

Double-ended breaks are simulated with the valve disposition as shown in Fig.4.38.

4.4.3 ADS break line

The ADS break line is located on the ADS single train simulation pipe, upstream of the safety valve, and enters the Dry Well at the same elevation. Fig.4.39 shows the flow diagram.

Small breaks are foreseen and the break size is defined in the test matrix. Proper break orifices set the desired flow.

4.4.4 Feedwater Line break

The FL break is located within the containment. The break line connect the FL to the containment tank, in particular to the Reactor cavity DVI room.

The break size is defined in the test matrix.

Fig.4.40 and Fig.4.37 show the flow diagram.

4.4.5 Steam Line break

The SL break is located within the containment. The break line connect the SL to the containment tank, in particular to the Dry Well.

The break size is defined in the test matrix.

Fig.4.41 and Fig.4.42 show the flow diagram.

Fig.4.1– SPES3-IRIS facility components located on the load-bearing structure, front and side view

(a, c)

Fig.4.2 – SPES3-IRIS facility components located on the load-bearing structure, second floor

(a, c)

Fig.4.3 – SPES3-IRIS facility components located on the load-bearing structure, third floor

(a, c)

Fig.4.4 – SPES3-IRIS facility components located on the load-bearing structure, fourth floor

(a, c)

Fig.4.5 – SPES3-IRIS facility components located on the load-bearing structure, fifth floor

(a, c)

Fig.4.6 – SPES3-IRIS facility components located on the load-bearing structure, sixth floor

(a, c)

Fig.4.7 – SPES3-IRIS facility components located on the load-bearing structure, seventh floor

(a, c)

Fig.4.8 – SPES3-IRIS facility components located on the load-bearing structure, eighth floor

(a, c)

Fig.4.9 – SPES3-IRIS facility components located on the load-bearing structure, ninth floor

(a, c)

Fig.4.10 – SPES3-IRIS facility components located on the load-bearing structure, tenth floor

(a, c)

Fig.4.11 – SPES3-IRIS facility components located on the load-bearing structure, eleventh floor

(a, c)

Fig.4.12 – Primary system and containment flow diagram

(a, c)

Fig.4.13 – Secondary system flow diagram – Loop A

(a, c)

Fig.4.14 – Secondary system flow diagram – Loop B

(a, c)

Fig.4.15 – Secondary system flow diagram – Loop C

(a, c)

Fig.4.16 – Auxiliary system flow diagram

(a, c)

Fig.4.17 – RPV

(a, c)

Fig.4.18 – Fuel bundle cross section

(a, c)

Fig.4.19 – Heater rod spacer grids

(a, c)

Fig.4.20 – Fuel bundle box inner layer and grids

(a, c)

Fig.4.21 – Fuel bundle box

(a, c)

Fig.4.22 – Fuel box upper guide

(a, c)

Fig.4.23 – RPV bottom closure and seal system

(a, c)

Fig.4.24 – Riser and SG tube rows radial position

(a, c)

Fig.4.25 –SG tube rows positioning plates

(a, c)

Fig.4.26 – Pump connection to RPV

(a, c)

Fig.4.27 – Water distribution plates at SG inlet

(a, c)

Fig.4.28 – EBT

(a, c)

Fig.4.29 – EHRS A/B (2/8 loops)

(a, c)

Fig.4.30 – EHRS C (4/8 loop)

(a, c)

Fig.4.31 – Dry Well

(a, c)

Fig.4.32 – Quench Tank

(a, c)

Fig.4.33 – Pressure Suppression System

(a, c)

Fig.4.34 – LGMS

(a, c)

Fig.4.35 – Reactor Cavity and DVI room

(a, c)

Fig.4.36 –DVI line connection to the RPV

(a, c)

Fig.4.37 –DVI break line (lower break)

(a, c)

Fig.4.38 –EBT (CVCS) break line (upper break)

(a, c)

Fig.4.39 – ADS break line

(a, c)

Fig.4.40 – Feedwater line break

(a, c)

Fig.4.41 – Steam line break

(a, c)

Fig.4.42 – Steam line break connections to Dry Well

(a, c)

5. INSTRUMENTATION

A list of instrumentation for the SPES3 facility is given in Tab.5.1.

The list includes the traditional instrumentation, i.e. fluid and wall temperature, pressure and differential pressure measurements, and indicates those required quantities, (e.g. two-phase flowrates) that need to be measured by other devices that must be defined.

The SPES3 facility components have been numbered according to the IRIS plant model and each instrument label refers to a specific component (by its number). A number in consecutive order follows and indicates if more instruments are installed on the same component.

The instrument characteristics are reported in Tab.5.1 which columns have the following meaning:

- Location: position of the instrument on the plant;
- Instrument type: type of instrument used for the measurement;
- Manufacturer;
- Instrument model: is the specific model declared by the manufacturer;
- Plant code: SPES3-IRIS facility instrument identification code;
- SIET register: SIET instrument identification code;
- HP tap: identification of the plant pressure tap connected to the instrument high pressure side;
- LP tap: identification of the plant pressure tap connected to the instrument low pressure side;
- P1 and P2 (t.i., el.): pressure measurement position P1 and P2 identified by the pressure tap identification and the elevation (m) given with respect to the plant zero reference;
- Nozzle elevation: elevation, with respect to the reference, of the hole in a nozzle where the manometrical pipe comes outside from an in-component pressure tap;
- P1 and P2 hsl1 and hsl2: height of saturated liquid (m) is the elevation difference between the in-component pressure tap and the nozzle point where the instrument manometrical line exits the component, in case the internal portion of line is full of saturated water;
- P1 and P2 hss1 and hss2: height of saturated steam (m) is the elevation difference between the in-component pressure tap and the nozzle point where the instrument manometrical line exits the component, in case the internal portion of line is full of saturated steam;
- Instrument elevation: pressure instrument elevation;
- h: elevation difference (m) between the pressure taps P1 and P2;
- Span: instrument calibration range;
- M.U.: engineering measurement units;
- LRV.: lower range calibration value;
- URV.: upper range calibration value;
- hcl: net cold liquid height (m) is the elevation difference between the nozzle point, where the instrument manometrical line exits the component, and the instrument position (for the pressure measures), while it is the elevation difference between the points on the nozzles related to P1 and P2 pressure taps (for differential pressure measures). It is the value read by the Data Acquisition System (DAS);

- hsl net: net saturated liquid height (m) considering the P1 and P2 hsl (it is the value read by the DAS);
- hss net: net saturated steam height (m) considering the P1 and P2 hss (it is the value read by the DAS);
- M: instrument conversion constant (M.U./mV) (value read by the DAS);
- Q: instrument additional constant (M.U.) (value read by the DAS);

The utilization of all above said parameters is described in Appendix 1.

The instrument range will be defined once code simulation of the facility will be availble.

5.1 The Primary and containment system instrumentation

The instrumented flow diagram of the primary system and containment is shown in Fig.5.1 and instruments are listed in Tab.5.1.

5.1.1 Rod bundle thermocouples

The horizontal distribution of the instrumented heater rods is shown in Fig.5.2 with the thermocouples distribution at different levels in Fig.5.3, Fig.5.4, Fig.5.5, Fig.5.6, Fig.5.7.

A total number of 140 wall thermocouples is installed on the heater rods at 10 different levels with the criterion of having more instruments at the top than at the bottom. Level 0 is the Bottom of Active Fuel (BAF) while Level 10 is the Top of Active Fuel (TAF).

The rod bundle thermocouple label contains the component number and also an indication of the level and rod number where the TC is installed, Tab.5.1, Tab.5.2.

In order to protect the bundle during the LOCA transients, the two hot rods are more instrumented at the top and this should allow to detect eventual core uncovering and shut down the power before damages.

5.1.2 Special instrumentation

Instrumentation suitable to measure two-phase flow at the break lines remains TBD. The team is considering several options. The measurement points are indicated in Fig.5.1 and Fig.5.9 and listed in Tab.5.1.

5.2 The Secondary and safety systems

The Secondary and safety systems instrumentation is listed in Tab.5.1 and shown in Fig.5.8, Fig.5.9, Fig.5.10 for Loop A, B and C, respectively.

Tab.5.1: SPES3-IRIS facility – Instrumentation list

(a, c)

Tab.5.2: SPES3-IRIS facility – Rod bundle thermocouples

(a, c)

Fig.5.1: SPES3-IRIS facility – Primary and containment systems instrumented flow diagram

(a, c)

Fig.5.2: SPES3-IRIS facility rod bundle instrumentation

(a, c)

Fig.5.3: SPES3-IRIS facility rod bundle instrumentation – level 1 and 2

(a, c)

Fig.5.4: SPES3-IRIS facility rod bundle instrumentation – level 3 and 4

(a, c)

Fig.5.5: SPES3-IRIS facility rod bundle instrumentation – level 5 and 6

(a,c)

Fig.5.6: SPES3-IRIS facility rod bundle instrumentation – level 7 and 8

(a,c)

Fig.5.7: SPES3-IRIS facility rod bundle instrumentation – level 9 and 10

(a,c)

Fig.5.8: SPES3-IRIS facility Secondary and safety system instrumented flow diagram (Loop A)

(a, c)

Fig.5.9: SPES3-IRIS facility Secondary and safety system instrumented flow diagram (Loop B)

(a, c)

Fig.5.10: SPES3-IRIS facility Secondary and safety system instrumented flow diagram (Loop C)

(a, c)

6. DATA ACQUISITION AND CONTROL SYSTEM

The Data Acquisition and Control System relays on National Instruments Hardware and **[ ]**$^{(a,c)}$ software.

A proper software based on **[ ]**$^{(a,c)}$ will be developed to record and elaborate all the quantities.

7. CONCLUSIONS

This document summarizes the SPES3-IRIS facility design status at June 2007.

It describes the main adopted scaling principles and the solutions adopted to simulate the IRIS reactor components and puts in evidence those aspects that still need to be defined.

A scaling, mechanical and manufacturability verification is in process for all components by those partners of the project who are assigned of such tasks.

An instrumentation list and the instrument positions on the circuits are reported with the need of defining the use of special device to measure two-phase flow where required.

Once the component mechanical particulars and the piping layout will be finalized, the information contained in this document will be used to build a numerical model of the facility for the Relap5 code, suitable to simulate the system behaviour and give feed-back information for the final facility design.

8. REFERENCES

[1] Westinghouse Electric Company: IRIS Plant Description Document. WCAP-16062-P. March 21, 2003.

[2] International Standard CEI IEC 584-1. September 1995: Thermocouples.

[3] International Standard CEI IEC 751. Industrial Platinum Thermometer Sensors.

[4] Standard UNI EN ISO 5167-1,2,3,4: October 2004. Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full.

APPENDIX 1. DATA REDUCTION

The electric signals coming from the plant are converted in engineering quantities and derived quantities by means of a properly developed software relying on the **[ ]**$^{(a,c)}$ program.

A1.1 Directly measured quantities

The directly measured quantities are:

- temperatures;
- absolute or relative pressures;
- differential pressures;
- volumetric flowrates;
- others (related to special instrumentation) to be defined as needed.

Temperature

The fluid temperature is measured using Nickel-Chrome/Nickel-Aluminium sheathed K-type thermocouples and PT100 type Resistance Thermal Detector (RTD).

The CEI-IEC 584-1 standard for thermocouples provides a matrix voltage E (μv) - temperature T (°C) where the temperature values are derived from [2].

The CEI-IEC 751 standard for Platinum Thermometer Sensors provides a correlation that transforms the measured RTD resistance (Ω) in temperature (°C) as reported in [3].

Absolute pressure

The absolute and relative pressure electric signals in (mV) are converted into engineering units (S.I.) using the following linear formula:

[ ]$^{(a,c)}$

where:

- P = absolute pressure measurement;
- **[ ]**$^{(a,c)}$ pressure value measured by the instrument;
- mV = electrical signal coming from the instrument;
- M and Q = instrument calibration constants;
- C = 0 if an absolute pressure measurement instrument is used;
- C = atmospheric pressure value if a relative pressure measurement instrument is used;
- K = instrument hydraulic head, calculated as follows:

[ ]$^{(a,c)}$

where:

- g = gravity acceleration constant = 9.80665 m/s^2;
- h_{CL} = elevation difference (m) between instrument and external vessel pressure tap;
- ρ_{CL} = cold water density (assumed = 1000 kg/m^3);
- h_{SL} = elevation difference (m) between the internal vessel pressure tap and the point the instrument connection line exits vessel when the internal hydraulic line is full of saturated water;
- ρ_{SL} = saturated water density (kg/m^3) calculated at a specified reference pressure;
- h_{SS} = elevation difference (m) between the internal vessel pressure tap and the point the instrument connection line exits vessel when the internal hydraulic line is full of saturated steam;
- ρ_{SS} = saturated steam density (kg/m^3) calculated at a specified reference pressure;

Differential pressure

The differential pressure electric signals in (mV) are converted into engineering units (S.I.) using the following linear formula:

[ ]$^{(a,c)}$

where:

- DP = differential pressure measurement between two pressure taps in a component or pipe, Fig.A1.1;
- **[ ]**$^{(a,c)}$ differential pressure value measured by the instrument. The ± sign of DP_{inst} depends on the instrument installation on the plant, Fig.A1.1;
- mV = electrical signal coming from the instrument;
- M and Q = instrument calibration constants;
- K = instrument hydraulic head

The hydraulic head is calculated considering the geometrical configuration of the manometrical lines for each instrument. Three different conditions of the fluid inside the single manometrical lines can be possible on the base of the zone where they are installed:

- cold water for plant external lines;
- saturated water for some plant internal lines;
- saturated steam for some plant internal lines.

So, the hydraulic head can be expresses as:

[ ]$^{(a,c)}$

where:

- g = gravity acceleration constant = 9.80665 m/s^2;
- h_{CL} = net height (m) of the plant external hydraulic connection lines full of cold water (cold head);
- ρ_{CL} = cold water density assumed = 1000 kg/m^3;
- h_{SL} = equivalent height (m) of the plant internal hot hydraulic connection lines full of saturated water;
- ρ_{SL} = saturated water density (kg/m³) calculated at a specified reference pressure;
- h_{SS} = net height (m) of the plant internal hot hydraulic connection lines full of saturated steam;
- ρ_{SS} = saturated steam density (kg/m³) calculated at a specified reference pressure;

The ± sign of cold and saturated heads depends on the instrument installation on the plant.

Volumetric flowrates

For the turbine flowrate measurement devices, the volumetric flowrates are converted into electric signals (mV) according to a calibration curve:

[ ]$^{(a,c)}$

- mV = electrical signal coming from the instrument (mV);
- M and Q = instrument calibration constants.

A1.2 Derived quantities

The derived quantities are:

- mass flowrates by: nozzles, orifices, turbines, level variation rate;
- liquid levels;
- water and steam properties.

A1.2.1 Flowrate measures by nozzles and orifices

The reduction formula used to obtain the mass flowrate is:

[ ]$^{(a,c)}$ (kg/s) [4]

where:

- F = mass flowrate;
- α = flowrate coefficient;
- ε = compressibility coefficient (for liquid ε = 1);
- d = orifice throat diameter;
- ρ = fluid density upstream of the nozzle or orifice;
- DP = local pressure drop across the nozzle or orifice.

The coefficients α and ε are calculated on the basis of the EN ISO 5167-1-2-3-4 standard [4]. In case the geometry or flow conditions does not allow the standard application, the α coefficient is obtained by orifice calibration.

The steam isoentropic exponent σ = 1.27 is used in the ε calculation.

The actual values of the pipe inner diameter D and throat diameter d are corrected to take into account the thermal expansion of the material at the operating temperature:

[ ]$^{(a,c)}$;

[ ]$^{(a,c)}$;

where:

- T_{op} = operating temperature (°C);
- T_{amb} = fluid temperature (20 °C);
- λ = linear thermal expansion coefficient of the material (1/°C).

A1.2.2 Mass Flowrate measures by turbines

The turbine mass flowrate is obtained by:

[ ]$^{(a,c)}$ (kg/s)

where:

- Q = direct measured volumetric flowrate (m^3/s);
- ρ = water or steam density (kg/m^3);

A1.2.3 Flowrate measures by level variation rate

The liquid flowrate entering or exiting a tank can be obtained as level variation, known the tank geometry and the fluid density.

The general formula for the flowrate is:

[ ]$^{(a,c)}$ (kg/s)

where :

- $\frac{\Delta L}{\Delta t}$ = variation of tank liquid level during a certain accumulation time interval (m/s);
- $\frac{\Delta V}{\Delta t}$ = variation of tank liquid volume during the accumulation time interval (m^3/s);
- A = cross section area of the tank (m^2);
- ρ = water density (kg/m^3);

If the tank cross section area is variable with the height, it must be kept into account in the formula.

A1.2.4 Liquid level measures

The collapsed level is calculated by:

[ ]$^{(a,c)}$ (m)

where:

- DP = differential pressure between the pressure taps in a component or pipe;
- g gravity acceleration = 9.80665 m/s^2;
- ρ_L = water density (it can be saturated, subcooled or average water density) (kg/m^3);
- ρ_{SS} = steam density in saturation conditions (kg/m^3);
- h = elevation difference between the pressure taps (m);
- L_0 = elevation difference between the lower pressure tap and a reference elevation (m).

A1.2.5 Average density and void fraction measures

In case the local and friction pressure drops are low and negligible in a component, an average density (ρ^*) can be obtained by a differential pressure measure:

[ ]$^{(a,c)}$

where:

- DP = differential pressure measure (Pa);
- h = elevation difference between pressure taps (m);
- g = gravity acceleration = 9.80665 (m/s^2)

The void fraction α can be obtained from the average density by:

[ ]$^{(a,c)}$

[ ]$^{(a,c)}$

where:

- ρ_{SL} = saturated liquid density (kg/m^3);
- ρ_{SS} = saturated steam density (kg/m^3);

A1.2.6 Water and steam properties

All the water and steam properties needed for the calculation of derived quantities are obtained by properly developed and tested functions that provide such quantities versus measured pressures and temperatures in the plant.

Fig.A1.1: Scheme of the differential pressure measure calculation

P1 and P2 represent the pressure tap locations on a component or pipe.

P+ (HP tap) and P- (LP tap) represent the instrument hydraulic connections.

DP = (Pressure at point P1 – Pressure at point P2) is the differential pressure measurement.

(a,c)

In case of saturated water or steam heads, the hydraulic head H is calculated by adding the various contributions.