# PIACE NEWSLETTER

## *Issue 1*

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## *Message from the Coordinator*

*When in the 1942 Fermi activated the first atomic pile, a team of experts was ready to flood the pile from the top with a solution of cadmium salt, in case the control rods failed. A lot of progress in the safety systems has been done since that time and a step over is anyway required for the new reactors generation. Sustainability and safety improvements are the challenges of the new generations of fission nuclear reactors. Safety involves the largest interest of scientific community, which is pushing to provide technological solutions with high reliability and efficiency. In this framework, I am very glad to present the project PIACE (Passive IsolAtion CondensEr) which will provide a significant contribution to the safety improvement of the present and future technology of nuclear reactors. The project will demonstrate the feasibility and reliability, shortening the time to market, of an innovative Decay Heat Removal (DHR) system, based on an isolation condenser with non-condensable gases, able to manage the variable decay heat in passive way. The innovative concept has the important peculiarity to be completely passive, and the flexibility to be adapted both for the liquid metal and water cooled reactors. Two main branches can be identify in the project, a design assessment, with the support of numerical codes, to analyse the applicability of the concept to the different reactors technologies, and an experimental investigation to test the feasibility and the performance of the system.*
*The project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847715. It is an international collaboration which involves eleven European partners (ANN-Italy, EA - Spain, ENEA- Italy, GEN ENERGIJA - Slovenia, JSI - Slovenia, RATEN - Romania, SCK•CEN - Belgium, SIET - Italy, SINTEC - Italy, TRACTEBEL- Belgium and UPM - Spain), and is coordinated by ENEA. Each partner has huge expertise in the different reactors technologies, assuring a reliable contribution to the analysis of the system. The experimental tests will get advantage of the facility SIRIO located in Italy in the SIET laboratories. The facility is conceived for feasibility testing on this new DHR system and it will be easily adaptable for the tests in PIACE.*
*With these perspectives, I am very confident in the success of the project and of this innovative system, which will give a further boost in direction of safe nuclear reactors. Do not miss the opportunity to be part of this. Follow us.*

## *Project's Overview*

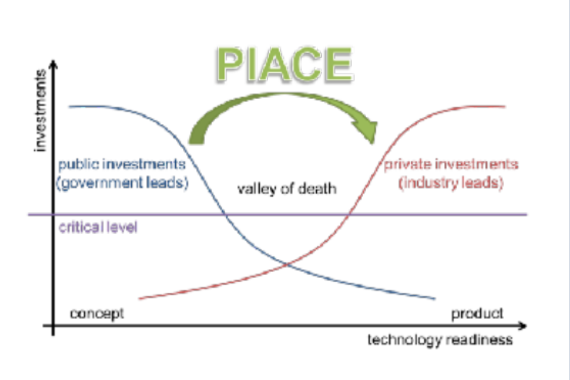
The "PASSIVE ISOLATION CONDENSER" (PIACE) is a project developed to address the performances of an innovative Decay Heat Removal (DHR) system based on an isolation condenser complemented with a tank of non-condensable gases [1] , to manage the variable decay heat in passive way. The project goal is to deliver a scaled-up conceptual design validated for LFRs/ADSs, LWRs (PWR&BWR) and PHWR applications. The innovative DHR concept is expected to **increase the safety and protection level** of both innovative fast reactors cooled by liquid metal (LFRs/ADSs) and in the present fleet of water cooled reactors currently in operation. Nuclear reactors are usually equipped with a safety system (or engineered safety feature), typically named Decay Heat Removal (DHR) or Residual Heat Removal (RHR), able to remove the residual heat (decay heat) from the primary system, following a Design Basis Accident (DBA), once the plant has reached a safe shutdown state. In most of the current industrial technology such systems are of "active" type, i.e. a continuous source of energy is required to guarantee the operation of pumps and other components which assure a fast and reliable operation of the DHR. In order to improve the safety levels, in the last years, with the advent of Gen III and innovative nuclear reactors, the nuclear community is driving the efforts to develop "passive" heat removal systems, i.e. systems not requiring energy sources for their operation; systems for which the circulation of the cooling fluid is based on physical principles (e.g. gravity) and generally compliant with IAEA directives.

The operation of a passive system, being based on physical laws and geometry of the system, is governed by the sizing of the system itself and, obviously, cannot be actively controlled, with important effects on expected transient behavior. This can be better understood through a practical example. After reactor shutdown, the decay heat decreases over the time asymptotically from the initial maximum value, on which the DHR system sizing is normally based. Therefore, in the evolution of the transient, a progressive over-cooling of the reactor's primary coolant takes place, unless the system has a means of self-regulation. This situation leads, in the case of high melting point cooling fluid (such as liquid metals, molten salts, etc.) to the possibility of freezing the primary fluid with sensible reduction of natural circulation. In the case of water cooled reactors, it would induce a strong depressurization of the system, with an associated sudden reduction of the temperature and thus high thermal stresses with a risk of loss of structures integrity.

This project develops a passive DHR based on coolant boiling and its subsequent condensation, capable to self-regulate the amount of exchanged heat following the reduction, over the time, of the decay heat. In this way it is possible to delay the freezing of the primary fluid (in the case of fluids with high freezing point) or to reduce the temperature gradients within acceptable limits, in case of light water cooled reactors. This is done in a passive manner (without the use of any active component), through the use of a non-condensable gas tank coupled to the system. The innovative DHR concept is patented by ANSALDO NUCLEARE- ANN (Italian Patent MI2013A001778 [1]) and, being actively actuated and operated without any energy source supplied is classified as an IAEA passive category D.

The main goal of PIACE project is the finalization of specific designs of the innovative isolation condenser (IC) system concept, ready for industrial implementation on several reactor technologies ranging from currently operating plants (light and heavy water reactors) to innovative energy systems (including FRs and ADSs). The innovative IC system concept proposed in PIACE will advance its technological readiness to level 7, gaining an actual chance to reach the market. At the conclusion of the project, industry will inherit from research a well-formed package of technical information, incorporating experimental results of prototypical operation of the system, meant for direct application to existing or future systems. The PIACE project will significantly contribute to materialize the ambition of a continuous increase of the safety standards in the nuclear domain, by directly and extensively addressing a number of activities that are typical of the so called "valley of death": the stage, in the process of concept development from idea to the market, where research falls short and industry is still reluctant to take the lead, as illustrated in the figure.

*Representation of the roles of research and industry in the development of a product, and of the so called "valley of death"*




To reach its main goal, the project is organized into a set of practical objectives each referring to a stage and a specific activity of the project: (1)Evolution of the concept into existing designs; (2)Demonstration of feasibility and measurement of expected performance; (3) System scaling, experimental results and validation of industrial design codes; (4) Definition of an exploitable technical product for the specific technology. The activities planned in this project are directly linked to the main challenge of delivering to industry a well characterized design of the innovative ICS, specifically tailored for application to each of the selected types of reactors.

A well-defined sequence of activities is going to be performed in a four step route: (1) The starting phase focuses on performing some confirmatory studies for HLM applications and adapting the innovative ICS concept specifically to the other reactor technologies, thereby aligning all the five concepts (namely LFR, ADS, PWR, BWR, PHWR) to the same maturity level. (2) The definition of an experimental test matrix of each reactor type for the experimental characterization and the choice of two significant (possibly bounding) reference cases for experimental test on SIRIO experimental facility made available by ENEA and SIET, are envisaged in this step. (3) For the two selected cases and for LFR technology (being ALFRED the technology demonstrator ) specific tests on SIRIO facility and post-test analyses will be performed. (4) Finally, specific designs of the innovative ICS will be set-up, starting from the drafting of detailed technical specifications and ending up with the drawing of a scaled-up model, each meant for application to one of the reference reactor technologies.

## *Project Impact*

PIACE will significantly support European organizations in reaffirming their worldwide-acknowledged leading position in nuclear science and technology, and notably in nuclear safety. The availability of a common system for DHR in all reactor technologies presently and prospectively operating in Europe (and, to a very large extent, in the whole world) could be a unique opportunity for the further harmonization of the safety standards and approaches. In turn, this would facilitate and strengthen the process of implementation of the European legislation and ensure the alignment of all plants' performances to new standards, scoring well beyond those presently available. In PIACE, a new, virtuous model of technology transfer will be experimented, improving trust-based sound connections among the partners of the consortium. A successful experience in the nuclear field will stimulate spontaneous collaborations between research and industry in the future, thereby facilitating the aimed continuous and long-lasting process of industrial innovation. The safety enhancement implied (directly and indirectly, as mentioned above) by the use of the delivered innovative IC system, both for the presently operating reactors and in future energy systems, will significantly improve the public perception on the efforts, and the consequent success, in protecting the public and the environment. As a direct consequence, a broader consensus on an energy source no longer perceived as a threat might facilitate a more extensive deployment of nuclear, to the sake of environmental protection (being a carbon-free source) and societal equity (being an affordable source). This might turn to be a main booster to the actual implementation of the European energy policies, which are, indeed, based on the pillars of safety, sustainability and security of supply.

## *PIACE Structure*

PIACE Project is funded under the Grant Agreement 847715 between the European Commission and ENEA on behalf of the Project Consortium, in the framework of the Euratom research and training programme 2014-2018. The estimated cost of the action is slightly more than 3 million euros, for a staff effort of nearly 400 man-monts over a 3 years period of duration (2019 – 2022).
PIACE is organized in 4 technical work packages (WP1 to WP4), plus a work package dedicated to dissemination (WP5) and one to the coordination of the consortium (WP6).

*WP1 - System analysis behavior*
The WP is aimed at confirming the advantages of an Isolation Cooling System based on noncondensable gases for both current and future reactor technologies, by selecting and analysing in details the plant behaviour against the most limiting Design Basis Accident (DBA) for each technology. In order to demonstrate the increased robustness of the plant against extreme and unlikely event, in compliance with the EURATOM Safety Directive, additional more limiting Beyond Design Basis Accidents (BDBA) will be also assessed.

*WP2 - Test Matrix definition for SIRIO facility*
The WP aims at defining, supported by a pre-test analysis performed by the use of STH code (e.g.RELAP5, TRACE, APROS, etc..), the applicability of the SIRIO facility to technology validation and the necessary test matrix for each reference reactor technology..

On the basis of the results from the transient analyses carried out for each reactor technology in WP1, the main phenomena controlling the system behaviour will be identified. In the pre-test phase, numerical models will be used to analyse the scalability of the system and the representativeness of the SIRIO facility, once adapted at conceptual level to the system under investigation. The test matrix will identify the minimum set of experimental runs necessary to catch the controlling phenomena. Beyond the information collected to validate the technology performance of the isolation condenser DHR system, when applied on each reference reactor, the test matrix will be conceived also to cover the needs to assist the process of verification and validation of STH computational codes, to be further used in WP4. Due to the peculiarities of each reactor technology and related controlling phenomena, a detailed description of the upgrading needs, will be provided for each reference systems (except for LFR reference reactor). The study will provide the basis for the selection (foreseen as part of WP3) of the experimental campaigns for two additional reference cases.

*WP3 - Technology Demonstration in Relevant Environment*
The WP is devoted to the experimental campaigns needed to increase the system TRL. In particular, the SIRIO facility will be upgraded and the performance of the innovative DHR will be characterized experimentally, both for the LFR (ALFRED) configuration and for additional two reference technologies test cases. Thanks to a national funding opportunity from Italy, the SIRIO facility was erected with the goal to study and completely characterize the innovative, passive and self-regulating isolation condenser system based on non-condensable gases. Since the SIRIO configuration was based on the scaling down of ALFRED, the first run planned in the WP will be relevant for LFR. Further tests will be then performed, considering other two reference test cases, potentially needing an upgrade of SIRIO to make the facility fully representative. The choice of two additional reference test cases to be experimentally simulated will be based on the amount of investments and related time efforts needed for achieving the SIRIO upgrade, and according to the technological relevance of the proposed tests for any reference systems, according to the feedback received from the WP2.

*WP4 - System Prototype Design and System Analysis Behavior*
The WP activities will be devoted to the comparison of the experimental data with the pre-test analyses to solve any difference or scaling distortions, as well as to validate the computational tools and provide “best practices” guidance to capture the main underlying phenomena. Moreover, a technical specification of the safety system will be developed for each of the nuclear technologies under study, covering aspects like, but not limited to, system functions, system criteria, interface requirements, system performances, validation basis. The analyses of the benefits of the innovation in terms of plant robustness, traded off with the impacts deriving from its implementation (in terms of layout, civil structures, instrumentation and control, etc.), will be assessed for both existing NPPs, potentially benefitting from the technology, as well as for next generation reactors. The activities outcome will represent a perspective improvement in terms of TRL and will bring the innovation closer-to-the-market.

WP5 is devoted to dissemination, education and training activities, to create synergies with these platforms and networks to widen the outreach of their offer by covering aspects related to the challenges and opportunities of the technological innovation in the nuclear industry.

# *First Results*

## *WP1 - System analysis behavior (EA- Empresarios Agrupados, Spain)*

In PIACE Project, an innovative Decay Heat Removal System for nuclear reactors is scaled-down and demonstrated in a relevant environment (SIRIO facility). This system, which is under validation, is applicable to LFRs/ADSs and LWRs reactor technologies. For that purpose, in the first phase of the WP1 “System analysis behavior”, and for the mentioned reactor technologies, the DHR system has been analyzed by defining and selecting the most representative transient enveloping scenarios as well as integration within reactor architecture. For the LFR technology, ALFRED demonstrator was taken as reference plant. The DHR system guarantees that the Reactor Coolant System (RCS) temperature remain above the coolant freezing limit following the reference transient scenarios of Station Blackout having maximum heat removal capability. Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) already includes a condenser-based heat removal system. Since the aero-condensers (AC) of Secondary Cooling System (SCS) are already sized for MYRRHA design and it is proved that this system can ensure DHR function, the analysis of a scenario challenging the maximum decay heat removal is not foreseenin the Primary Heat Exchanger (PHX) to the freezing temperature.

For the rest of the reactor technologies (PWR, BWR, and PHWR) there is no risk of overcooling but the intrinsic characteristic of the safety system allows to strongly reduce the thermal and mechanical transients during its operation compared to other emergency cooling and injection systems. In the PWR the Passive Isolation Condenser is attached to the secondary system on the AFW pipeline and the outlet of the steam header, and the transient scenarios are all based on the case of station blackout where the main concern is to remove the decay heat after the reactor trip and thus to successfully prevent the core damage.

For the BWR, the reference reactor, the ESBWR, already has a condenser-based heat removal system. The transient scenarios are enveloped for these main events: a sudden reactor isolation at power operating conditions, during station blackout, and Anticipated Transient Without Scram.

Finally, in the PHWR, the DHR was designed to remove the residual heat generated in reactor core during a station black out accident for 72 hours. The safety philosophy is based on the concept of a single/dual failures, resulting design basis accidents events as feedwater line break and main steam line break.

In the Second Phase of the WP1, it has been developed / updated a model representative of the Decay Heat Removal System and, finally, numerical models to simulate the selected accident scenarios have been created for all the referenced reactors.

The ALFRED model, developed with RELAP5 3D, is characterized by 5 systems: the RCS, the three DHR loops, and the IC pool. The results highlight the ability of the passive power control system to clearly delay the freezing of the primary coolant extending the grace period.

In the MYRRHA model, where the analysis tool is RELAP5 MOD3.3, four AC as interface between SCS and TCS, non-condensables are passively added to the SCS.

The results indicate that the use of a nitrogen-based passive injection system (pressurized tank) allows to moderate the heat transfer in the Aero-Condenser, which limits the energy removal towards the ultimate heat sink, and to avoid overcooling and possibly freezing of the lead-bismuth eutectic coolant in the primary circuit over the 72h of the transient.
For the PWR, the computer code APROS was used to simulate the accident scenario in a two-loop PWR reactor, and the RELAP5/MOD3.3 was used to simulate the Passive Isolation Condenser in the closed loop. The simulation results show that the proposed concept of the Passive Isolation Condenser, with nitrogen ingression, should limit steam condensation (and thus decay heat removal) when the pressure decreases to a certain level.
The BWR model was also developed using the two-phase (water/steam) thermal-hydraulic code RELAP5/MOD3.3. The results indicate that the nitrogen covering the IC walls results in a degradation of the heat transfer resulting in smoother gradient and gentle slope for pressure and temperature.
Finally, the RELAP5/MOD3.2 is used for the PHWR model. Here, the value of the setpoint to open the atmospheric discharge valves are reached more rapidly, the water inventory of the secondary side of the steam generators is sufficient for 20 minutes after the break, the heat flux increased with pressure in the secondary side of the steam generator reaching almost the nominal value, and, if trip of all pumps of the PHT is considered, ASDV valves are opened again during the simulation.

***WP2 - Test Matrix definition for SIRIO facility (SCK-CEN, Belgian Nuclear Research Centre, Belgium)***

The WP2 aims at assessing the compatibility of the SIRIO facility with the different reactor technologies selected for the PIACE project. Specifically, a test matrix for each technology is defined to demonstrate the efficiency of the Isolation Condenser (IC) solution in delaying the primary system coolant freezing or smoothing the temperature gradients during accidental transient events for HLM and L/HWR, respectively.
The test matrix takes into account the results from the transient analyses on the full-scale plants performed in WP1. Such conclusions represent the starting point for the pre-test phase: numerical models used to analyze the scalability of the system and the representativeness of the SIRIO facility are then built and applied, leading to the finalization of the test matrix.
The pre-test analyses provide the basis for the selection of the experimental campaigns for two additional reference cases, foreseen in the frame of WP3.
Next to the IC technology validation, the test matrix is conceived also looking forward to the process of verification and validation of STH computational codes, intended to be further applied for the post-test analyses in WP4.
While LFR represents the reference, other reactor technologies requires the SIRIO facility to undergo a series of modification to meet the specific features and needs in terms of instrumentations, layout, main components and logical controls. Such specifications, together with the test matrix definition, represent the WP2 output for each reactor technology.
The WP2 is divided in five Tasks, each one dealing with one of the reactor technologies selected, under the responsibility of one of the WP participants. The main conclusions for each Task are reported.

**Task 2.1: Test Matrix definition for LFR reference reactor**

A system pressure increase, triggered by the isolation of the heat sink, causes the opening of the IC branch and consequent non-condensables injection. The power input follows the typical decay heat profile.

The simulations show that the conceptualized configuration of the facility allows to reproduce and to observe in a reliable way the characteristic phenomena driving the experimental activity. The numerical results obtained allow to address that the main phenomena of interest for the ALFRED safety system are effectively represented by the SIRIO experimental facility.

System pressure and temperature decrease during the transient is effectively slowed, leading to a notable delay in primary coolant freezing.

**Task 2.2: Test Matrix definition for ADS reference reactor**

The SIRIO facility model has been modified to better represent the selected ADS plant (MYRRHA) Decay Heat Removal system; in particular, the IC branch has been excluded and the non-condensables tank has been directly linked (through a closed valve) to the heat exchanger used for steady state.

A typical Protected Loss Of Forced Flow has been considered as transient event, leading to SIRIO pressure reduction that triggers the non-condensables tank valve opening.

System pressure and temperature decrease during the transient is effectively slowed, leading to a notable delay in primary coolant freezing.

A series of sensitivity analyses on the most influencing input parameters has been performed, allowing refining the understanding of the parameters' variation on the transient evolution.

**Task 2.3: Test Matrix definition for PWR reference reactor**

A number of modifications has been proposed to adapt the SIRIO facility to the representative PWR plant considered. To achieve the steady state, the heat exchanger surface was increased by a factor 1.82.

Concerning the transient, an isolation of the steady state HX causes the loop pressure to increase, eventually triggering the IC branch valve open and the activation of the IC. Power is driven by Decay Heat profile.

Two sensitivity studies has been performed, modifying the beginning of the Decay Heat during the transient and the non-condensables tank volume. The results have shown that, as expected, the peak temperatures are reached when the Decay Heat curve start is delayed, while a larger non-condensables tank causes a lower temperature peak.

**Task 2.4: Test Matrix definition for BWR reference reactor**

A complete TRACE5p5 model of SIRIO in its original configuration for both steady state and transient operation was preliminarily developed, obtaining results that are close to the ones from the original model.

A deep research of the DHR system in BWR and LFR technology has been made to perform a suitable adaptation to SIRIO.

Then, to overcome the discrepancies between BWR and LFR technologies, a wide range of proposals were calculated by testing SIRIO's available modifications:

Scaling proposal 1: adding an extra volume to emulate the BWR steam inertia, adding a valve to isolate the non-condensable tank, keeping the power density equal to SIRIO.
Scaling proposal 2: keeping the volume, using the HX at the same time as the IC branch and using the maximum SG power, adding a valve to isolate the non-condensable tank, keeping the power density equal to SIRIO.
The TRACE simulations shown that the scaling proposals are able to replicate the expected behavior for the fundamental thermal-hydraulic variables of the innovative DHR system.
Henceforth, SIRIO has been proven to be a suitable facility for testing the BWR innovative DHR design, provided the required modifications, with the natural limitations coming from the power and volume differences between a BWR and ALFRED.

**Task 2.5: Test Matrix definition for PHWR reference reactor (ICN-RATEN)**
The analysis of the comparison between the parameters of interest suggests that the scaling between the full-scale CANDU system and SIRIO is difficult to harmonize without revising the volumes. The analysis showed some differences between the CANDU system and SIRIO that are not immediately adaptable to a representative test.
It is thus necessary to review the design of the safety system on the CANDU representative plant with a higher number of analyses and work to integrate the passive safety system operation with respect to the control philosophy currently existing on the plant.
It is then possible to propose design changes to SIRIO involving an increase in water volume and a larger IC heat transfer surface.

***Upcoming Conferences and Events***

SNETP FORUM 2021, online, February 2-4, 2021
OECD/NEA workshop on reactor core and containment cooling system, Levice, Slovak Republic , Februry 23-25, 2021
European Joint Programme on Radioactive Waste Management (EURAD) 1st Annual Conference, March 16-18 , 2021
SMiRT 26, Berlin, Germany, August 8-13, 2021
IAEA Technical Meeting on State-of-the-art Thermal Hydraulics of Fast Reactors, Brasimone research Center, September 20-24, 2021

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