GEMINI Plus project for HTGR nuclear cogeneration demonstration

In September 2007, the *Sustainable Nuclear Energy Technology Platform* (SNETP) launched its activity in three major pillars: maintaining the safety and competitiveness of today's technologies, developing a new generation of more sustainable reactor technologies, and developing new applications for nuclear power. One of these pillars is implemented by the *Nuclear Cogeneration Industrial Initiative* (NC2I), which targets the development of a nuclear cogeneration solution for delivering process heat and steam, as well as electricity to industrial facilities, in replacement of fossil fuel-burning cogeneration plants. In line with SNETP deployment strategy for use of nuclear energy in non-electric applications, NC2I was launched to demonstrate industrial nuclear cogeneration and to federate actions at national and European levels. On the other hand, NGNP (Next Generation Nuclear Plant) Industry Alliance and NC2I two years ago decided to launch the GEMINI Initiative (*Trans-Atlantic Partnership to Accelerate the Development of High-Temperature Gas-cooled Reactors*) for facilitating this challenging phase by sharing the development efforts and the risks between the US and Europe. Endeavouring to maximise the convergence of safety approaches and related technological options of the High Temperature Gas-cooled Reactor (HTGR) systems on both sides of the ocean will allow sharing costs and risks of the programme and facilitating commercial deployment worldwide. Presently, GEMINI members are exploring the growth of this partnership towards consortia in other countries involved in HTGR development. Over the past 15 years, the US industry has invested over $1 billion in evaluating design trade-offs, early design and equipment qualification for HTGR technology. For demonstration of industrial nuclear cogeneration and to federate actions at national and European levels, the Euratom research projects were conducted in the past: RAPHAEL, EUROPAIRS, ARCHER and NC2I-R provided substantial results concerning safety aspects, coupling systems, fuel, materials, market knowledge, etc. So, GEMINI Initiative calls for a simple, transparent, accountable and strong agreement between the private sector companies to work with their governments under international agreement framework to carry out the design and regulatory work for the first commercial HTGR.

Before deployment at a significant scale, the demonstration of nuclear cogeneration has to tackle a number of challenges. In this undertaking, the FP7 project NC2I-R, being a coordination action project, has been built upon previous EUROPAIRS and ARCHER projects. Finished in 2015, NC2I-R project has enabled to improve knowledge on nuclear cogeneration and recognise its strengths and weaknesses, provide knowledge about safety of nuclear cogeneration plant, focused on potential licensing issues, create clear path towards constructing a specialised cogeneration plant, and provide links between nuclear community and industrial end-users of heat and electricity.

In 2017, a new H2020 project ***GEMINI Plus*** (*Research and Development in support of*

the GEMINI Initiative) was initiated, and it is the logical outcome of the past projects. The duration of the Project is 36 months. *GEMINI Plus* project will provide a conceptual design for a high temperature nuclear cogeneration system for supply of process steam to industry, a framework for the licensing of such system and a business plan for a full scale demonstration. A site for nuclear cogeneration plant demonstration is considered in Poland, where adequate industrial needs, political conditions and necessary infrastructure can be found. Nuclear cogeneration will rely on modular HTGR technology, which is a proven and mature technology with several industrial prototypes that have been constructed and operated in the world, and it makes this type of reactor feasibly deployable in a relatively short term. The time scale for the industrial deployment of such nuclear cogeneration systems is a decade. Experts estimate that the industry's demand for such a solution around the world is huge, only in Europe it is estimated at several hundred of such devices.

In comparison with other SMR designs, the modular HTGR has a specific asset: its operating temperature being higher than in other types of nuclear systems, it can address one of the possible missions of SMRs, i.e. cogeneration, on a wide range of applications that are not accessible to other nuclear reactors. In particular, beyond mere electricity generation, HTGR can address industrial process heat applications, the bulk of which requires temperatures that cannot be reached with Light Water Reactor (LWR) technology. With available materials and technology, such a system can provide steam to industrial steam distribution networks presently operating on industrial sites up to 550°C, simply substituting to fossil fuel fired cogeneration plants, without any need for adaptation of the steam distribution infrastructure or industrial applications. On the other hand, nuclear cogeneration at high temperature is by itself an innovative use of nuclear energy, with no previous experience. Therefore, the deployment of HTGR for industrial high temperature cogeneration does not only require the mastery of HTGR technology itself, but also of the coupling with end-users, calling for industrial scale demonstration before commercial deployment. In the longer term, HTGR technology can be further developed to provide higher temperature process heat, for instance, poly-generation, district cooling, H2 production, etc. The production of carbon free heat at temperatures approaching 700–900°C from advanced nuclear energy technology is a major innovation that can open large new markets for plant production systems and jobs for the future.

Based on its huge thermal inertia, its refractory fuel and core structural materials, on the use of helium, which is chemically inert, as coolant, and of a specific power limiting design, modular HTGRs have a unique intrinsic safety design, eliminating risks of significant core damage and radioactive releases in accident conditions. It can be a major contributor to the compliance of nuclear energy with the highest safety standards, even beyond the requirements of the EU Nuclear Safety Directive, and can open the possibility of co-locating nuclear cogeneration plants on conventional industrial sites, which is a prerequisite for industrial process heat supply. Beyond industrial cogeneration, the flexibility, robustness and simple design of modular HTGR will allow extending application of the system developed by *GEMINI Plus* to small isolated electric grids, to electric grids with increasing proportion of intermittent renewables, to new nuclear countries, etc.

All *GEMINI Plus* activities are structured within six Work Packages, covering the development of the assumptions and methods of licensing necessary to implement nuclear cogeneration technology, the identification the potential industrial heat recipients, the presentation of the recommendations for the construction of a European demonstrator and the indication of the directions for further development:

- WP1 – Safety Approach and Licensing Framework;
- WP2 – Configuration for an industrial high temperature nuclear cogeneration system;
- WP3 – Innovation and long-term perspective;
- WP4 – Demonstration project of industrial high temperature nuclear cogeneration;
- WP5 – Dissemination and Stakeholders engagement;
- WP6 – Project management and coordination.

The Project team is composed of 26 partners from public bodies, private companies, SMEs,

research organisations and universities, coming from 9 European countries, from the US, Japan and the Republic of Korea. Such international Project team will allow employing the very valuable developments performed in the US on the NGNP programme, with in particular the development and qualification of a very high performance HTGR fuel, with the experience of development and operation of the test reactor HTTR in Japan and with Very High Temperature Reactor programme in Korea. Lithuanian Energy Institute (LEI), representing one of TSO engaged, is a Consortium member of the Project. LEI scientists, with their nuclear competence in evolution of safety standards and regulations, are contributing to WP1 & 3 activities.

Taking into account the challenge of the *GEMINI Plus* project – to prove the industrial feasibility of coupling two mature technologies, the nuclear HTGR technology and the cogeneration technology – after accomplishment of all planned activities under this Research and Innovation Action Project, the following high-level objectives will be fulfilled:

- The basis of a licensing framework for the development of a new nuclear cogeneration modular HTGR addressing both the requirements of the amended Euratom Nuclear Safety Directive and other recent safety requirements will be established;
- Essential technical specifications of a nuclear high temperature cogeneration system complying with the highest safety standards will be defined, thus reinforcing EU commercial prospects and competitiveness;
- Significant contribution to the Energy Union and the SET-Plan objectives, in particular regarding decarbonisation of the European economy, safe and efficient use of nuclear energy, security of energy supply, and keeping industrial jobs in Europe, will be set up;
- Close convergence between the safety approach and the selected technological options and those selected by the NGNP Industry Alliance will be conducted;
- The basis for the development of an industrial demonstration of HTGR nuclear cogeneration with recommendations and plans for bridging possible residual gaps, if identified, will be established.

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