EDF Technology unveiled

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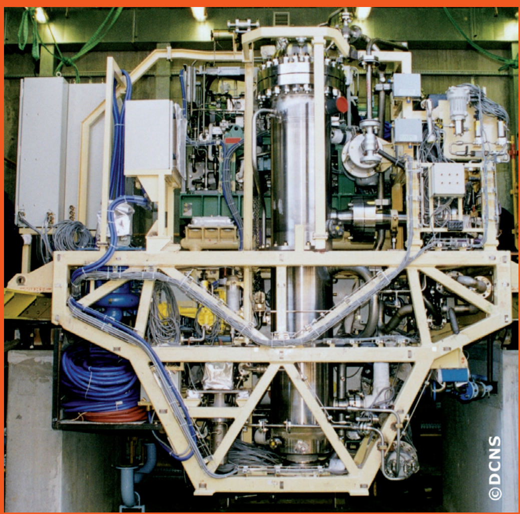


Modular construction

The emergence of mini-power plants

Although the scaling factor is favourable to large-scale reactors, small modular reactors offer other advantages:

- Manufacturing and testing are carried out in the factory, guaranteeing better construction quality, shorter assembly times on site and easier decommissioning. The installations of nuclear and conventional sub-assemblies are designed and manufactured in a modular way, each module being transportable by land or sea for assembly on site. This approach is broadly applied in the field of naval construction. The modular approach to the manufacturing process also involves civil engineering.
- The reactor's integrated architecture benefits from its modularity and offers advantages in terms of safety. The reactor vessel includes the core, the steam generators, the pressuriser and the primary coolant pumps, thus removing the need for primary coolant loops.
- A smaller investment means less of a risk, and projects can be funded on a gradual basis, making nuclear energy accessible to new players with limited financial capacity.

Small Modular Reactor (SMR)

A NEW TYPE OF PLANT FOR THE NUCLEAR INDUSTRY?

Nuclear energy has developed throughout the world along two lines in response to very specific needs: large-scale power generation and military naval propulsion, largely for submarines. The number of reactors and the technology employed in these two sectors are similar, with each relying on a few hundred reactors, most of which are PWRs (pressurised water reactors). Nonetheless, their unit powers are very different: around 1,000 MWe in the first case and the equivalent of a few dozen electrical Megawatts in the second. Although the development of nuclear electricity began with small reactors, a general trend towards large-scale reactors was to follow, due to an economy of scale linked to the sizes of the installations. However, for some time now, various countries involved in reactor design have been considering the development of plants with a power output of less than 200 MWe. Such reactors enable more compact and modular designs and are known as SMRs (small modular reactors).

Nuclear submarine

EDF's position

France is recognised worldwide for its excellence in the nuclear industry. It is also part of the exclusive club of naval propulsion reactor designers and operators. As a result, a consortium bringing together the CEA (Atomic Energy and Alternative Energies Commission), AREVA, DCNS and EDF was legitimately questioned on the relevance of the development of SMRs and arrived at a positive conclusion following a technical and economic feasibility study, carried out between 2012 and 2014.

Annie Diet, SMR Project Manager at EDF R&D.

SMALL IS BEAUTIFUL: A NEW DIRECTION FOR THE NUCLEAR INDUSTRY?

SMRs deliver a perfectly integrated solution

Energy procurement is one of the key political, economic and ecological challenges facing the future of our planet in the 21st century. Satisfying the world's energy demands and meeting international goals in the fight against climate change means that carbon-free energy sources must be developed. Nuclear power, therefore, appears to be a crucial component of the energy mix of the future.

Financing: a key advantage for SMRs

Access to nuclear energy has always been very closely linked to a country's economic weight and its GDP. Countries that have developed nuclear option have GDPs in excess of 200 billion dollars. Globalisation and trade liberalisation have significantly reshaped the allocation of wealth, and new countries are now achieving medium-size GDPs of between 40 and 200 billion dollars. However, this amount is still insufficient to finance large-scale reactors. Provided that the electricity market is not shared between smaller operators, resources on this scale might enable such countries to make limited investments, possibly of around 1 billion euros: an amount sufficient to fund a small-scale reactor. These medium-wealth countries with a recognised interest in using nuclear energy are known as 'first-time buyers'. In the same category are 'rich countries' with fragmented electricity markets, in which large-scale nuclear reactors are out of reach for some operators due to their insufficient investment capability. One such country is the United States, which has an interest in SMRs to help it replace its coal-fired plant fleet.

Large-scale reactors may also be of interest to medium-size electricity companies, in countries that already generate nuclear energy or that are keen to gain access but are concerned about balancing their energy mix.

Belleville Nuclear Power Plant

Small-scale reactors to complement their larger counterparts

Small reactors do not present competition, but are designed to complement their larger counterparts, operating within market segments where large reactors are inappropriate. This is the case in countries or regions with an isolated or insufficiently robust power grid. Small reactors can also have other uses, as they can be installed in close proximity to the activities that require them, such as co-generation, sea water desalination or hydrogen production in isolated regions where non-electrical applications are just as important as electrical power. However, this segment represents a niche market and its economic competitiveness remains to be evaluated.

KEY FACTS

1954: USS Nautilus, the first nuclear-powered submarine (General Dynamics, USA).

1957: Shippingport reactor, the first PWR-type nuclear reactor with a power of 60 MWe (Westinghouse, USA).

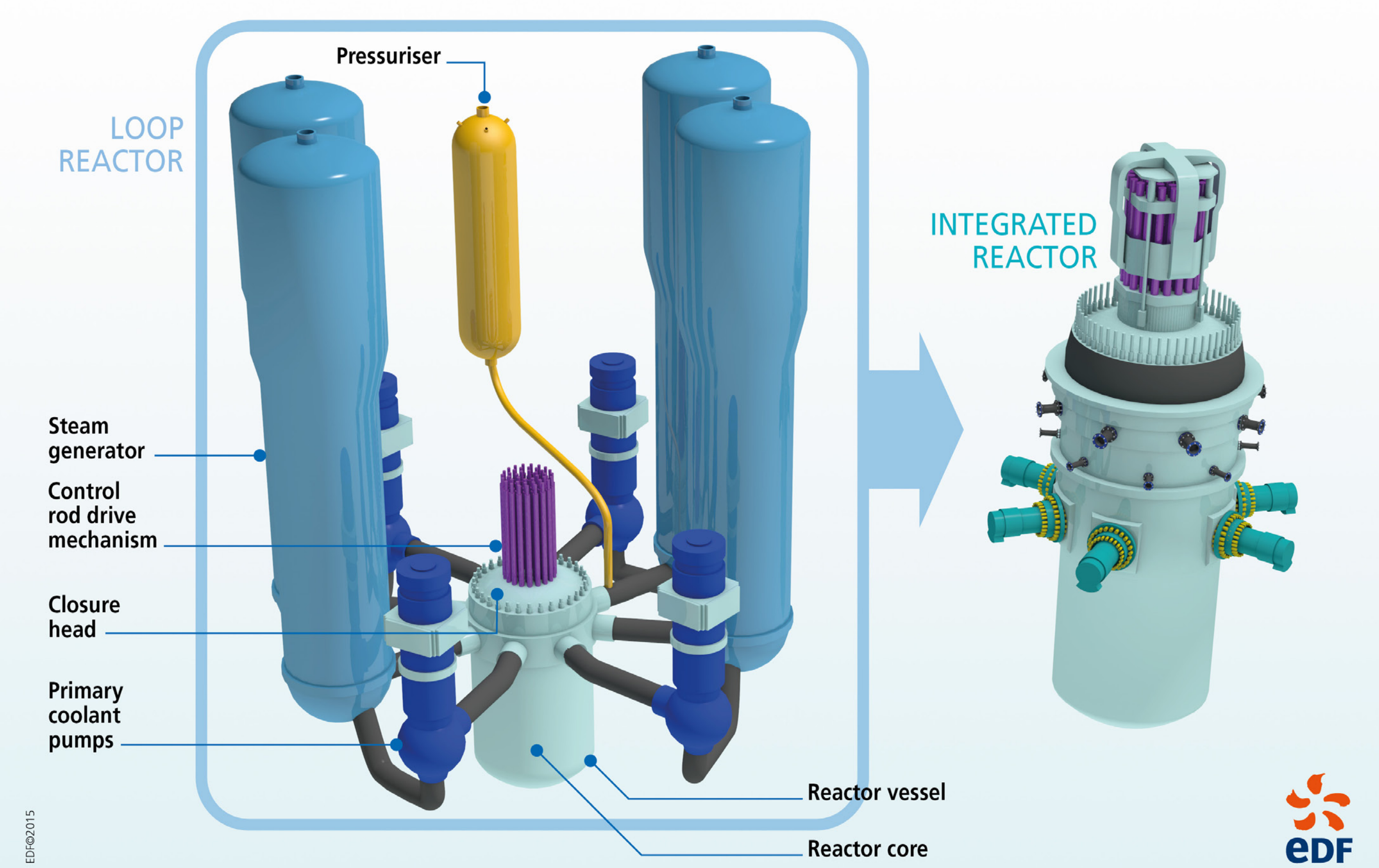
1964: PAT, the land-based prototype for a nuclear submarine reactor. This prefigured the steam supply system for the Redoutable, the French Navy's first ballistic missile submarine (SSBN), which entered active service in December 1971.

1967: First French PWR-type nuclear plant commissioned at Chooz, with a power of 300 MWe.

1975: CAP, the advanced prototype steam supply system. More compact than the PAT, this steam supply system would allow France to build nuclear-powered attack submarines, the smallest nuclear submarines in the world.

1977-1999: French nuclear plant pool's 58 units connected to the power network, with successive nameplate capacities of 900, 1,300 and 1,400 MWe.

SMR: FROM LOOP REACTOR TO INTEGRATED REACTOR



DID YOU KNOW?

The development of integrated reactors fits in quite naturally with the continuing work on naval propulsion reactors, for which only the pressuriser is installed outside the reactor vessel. These reactors operate without soluble boron, which simplifies the auxiliary systems and operating processes, while reducing the volume of waste produced. However, their direct transposition to SMRs is not feasible due to their very different sizes and operating condition requirements.

Safety advantages of an integrated architecture

The most mature SMR projects in the world involve pressurised water reactors, falling within the third generation category of nuclear reactors. Unlike large-scale reactors, the smaller size of SMRs enables them to have an integrated architecture, removing the need for primary loops, which, in safety analyses, present an initiating event for an accident if breached (loss of coolant). The compactness associated with this integrated architecture favours large-scale factory manufacturing, improving the quality of the assembly and reducing the amount of on-site work. It also enables the use of passive engineered safeguard systems for evacuating residual power. These rely heavily on gravity or on the natural circulation occurring as a result of the heating of the primary coolant in the lower part of the system together with its cooling in the upper part. The difference in specific gravity causes the coolant to circulate. These passive systems can operate without any human intervention for several days and do not require any external source of energy, offering a significant advantage in terms of safety. Benefiting from the natural circulation of fluid during normal operation, certain concepts may even dispense with primary coolant pumps all together. The characteristics of small modular reactors – low power combined with large pressure vessels means that in the event of a severe accident with a core meltdown, the corium will remain in the vessel, eliminating the need for a core catcher, which is required for the EPR. Managing the reactor with the control rods alone, in other words without soluble boron, also eliminates criticality risks due to unintentional dilution. This technological option, which has already been mastered on naval propulsion reactors, also requires a much simpler effluent treatment system. Finally, the power output range of these SMRs means that the reactor building can be either partially or completely buried, making it less vulnerable to external hazards (aircraft crashes, etc.).

Outlook

To offset the scale effect, which is unfavourable to SMRs, economic levers must be identified and analysed, starting with the series effect. Modular production in a factory proposes dedicated industrial equipment, which is only viable if an SMR is designed in a standard way and mass-produced.

Series effect key to the competitiveness of SMRs

The benefits of series production in a factory were assessed by naval construction sites. The generally accepted rule is the '1–3–8' principle: a task performed in a specialist workshop in a factory will take three times as long if it is carried out at a dedicated pre-assembly worksite and eight times as long on board a ship. Even though working at a conventional site presents fewer constraints than on board a ship, the benefits of factory production are clear and all the more significant, considering the costs involved in building an SMR.

International certification is vital

SMRs have different design and construction features compared to large-scale reactors, such as their power level, source term, integrated architecture, modular production and factory qualification processes. These specific features might facilitate the ability to meet certain safety requirements, but they also demand changes to regulations. The NRC (the United States Nuclear Regulatory Commission) is, therefore, developing a specific reference system for SMRs.

Seeking to standardise the regulatory framework at international level, as in the aeronautics field, would present a tangible area of interest. This would be a pertinent goal, as it would enable 'first-time buyer' countries to rely on certifications awarded by the safety authorities in the countries designing the reactors, based on a universally recognised framework for reference. The NRC's reference system would seemingly provide an indispensable basis for this standardisation. If the French and American safety authorities were to move forward together in this direction, such regulations would form an essential reference base, given the weight of these nations on the world's nuclear stage.

> for further information

Revue Générale Nucléaire - 2014, no. 2, March-April:

- J. Chénais, A. Diet, Y. Grondin, S. Perrier, 'L'approche française par le consortium SMR (CEA, EDF, AREVA, DCNS)'; article also available in English: 'The French approach through the SMR consortium (CEA, EDF, AREVA, DCNS)'
- P. Lepelletier, S. Danguy des Deserts (DCNS), 'La construction modulaire: 30 ans d'expérience dans le secteur naval, au service du nucléaire civil';

International Atomic Energy Agency: www.aiea.org

List of terms

Soluble boron: with its concentration constantly adjusted in the reactor coolant system's water, soluble boron is used for controlling the reactivity in pressurised water reactors by absorbing neutrons. The alternative method involves the use of movable control rods containing neutron-absorbing materials.

Corium: magma consisting of melted oxide and metal materials from the core of a nuclear reactor (fuel, fuel cladding, steels forming the structural elements of the core). Under the effect of the residual power, the temperature of the corium in the vessel is over ~2,500°C.

Steam generator: exchanges the heat between the primary coolant, heated by the nuclear fuel, and the feedwater which, in its steam state, drives the turbine connected to the generator.

Pressuriser: maintains the pressure in the reactor coolant system to prevent the water from reaching boiling point.

Residual power: heat produced by the core, subsequent to the chain reaction caused by the decay energy from the fission products.

Criticality risk: inadvertent triggering of a fission reaction in an uncontrolled chain. This reaction is accompanied by an intense emission of gamma radiation and neutrons.

Safety: set of provisions for guaranteeing the normal operation of a nuclear power plant, for preventing accidents or malicious acts, and for limiting their effects to protect workers, the public and the environment.

Engineered safeguard system: safety system activated following an accident to limit its consequences and return the reactor to a safe shutdown state.

Source term: nature, quantity and release kinetic of radioactive materials from a nuclear facility. Used for assessing the consequences of such a release into the environment.

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