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INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

INFORMATION MEMO

Small Modular Reactors

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Nuclear modular reactors of less than 300 MWe (or small modular reactors - SMRs) have sparked growing interest in the world for several years. For their promoters, they constitute a means of producing energy that can meet various needs, such as cogeneration1[1] or non-electrical applications (industrial heat, production of fresh water, of hydrogen etc.). They are a suitable solution for districts that are isolated or have limited infrastructure. Their designers also show off improved performance in terms of safety, thanks to intrinsic and passive safety systems. Some designs offer an architecture allowing the installation of several modules independent of each other to achieve a larger overall power (of the range of 600 - 800 MWe).

To answer the question of economic profitability, the SMR designers put forth a simplification of the design and a shorter duration of the construction phase by means of modular construction, standardization with the benefit of series production. Therefore, the SMR designers ask for harmonizing the safety requirements in force in countries wishing to acquire such reactors. Some of them believe that the safety requirements should be adapted due to the intrinsic safety features of these designs.

IRSN considers, on the contrary, that there is no need to revise downwards the safety requirements for SMRs. The simplification and the inherent safety features should benefit safety and the demonstration thereof through compliance with these requirements.

Around seventy designs are offered around the world. Apart from naval reactors, few SMRs are in operation, a few others are at an advanced stage of design (USA, China, South Korea, Argentina, United Kingdom, Canada etc.). Some designs have been recently certified in the United States or reviewed by the safety authority in Canada. Many other concepts, including those based on other than light water technologies, are under development (molten salt reactors, lead, sodium, high temperature, etc.). The level of maturity of these latter concepts remains however well below the level of maturity expected to initiate an authorization process.

This paper provides an overview of the main characteristics that SMRs can have in terms of safety compared to high power reactors and underlines some factors which are likely to ultimately impact their actual level of safety.

The level of safety of a nuclear installation obviously depends on the type of reactor, but also on the design and operating measures planned to prevent and limit the consequences of accidents, and on the quality of design,

[1] As for example generation of energy for large industrial facilities, as a replacement for coal or fuel power plants

or Diesel engines.

manufacture and operation. Due to their low power and small size, SMRs allow a variety of design choices, some of which may be favorable to safety. However, it should be noted that most designs call for innovative technical solutions, the feasibility and effectiveness of which remain to be demonstrated. In any case, only a detailed examination of the design choices and assumptions would allow the assessment of eventual safety gains compared to higher power reactors.

Favorable safety characteristics due to low power

Beyond the more limited quantity of radioactive material in a small reactor, there is, for a given technology, a scale effect depending on the power of the reactor. Thus, from the point of view of core neutronics, it can be emphasized that small sodium cooled fast neutron reactors have better safety characteristics compared to large sodium cooled reactors, due to a negative or zero sodium void effect. For light water reactors, the effect is less obvious. The possibility of designing reactors without boron is, on the other hand, an asset in terms of safety, by eliminating the risk of boron dilution accident and by reducing the production of effluents in normal operation.

Whatever the type of reactor, the residual power to be evacuated is less important in the event of an accident. It enables the combination of passive and active safety systems and should make it possible to improve safety through better diversification of the design safety provisions.

The limitation of the power, through the use of passive systems, leads in principle most SMR designers to display a grace period without human intervention of the order of 7 days for the evacuation of the residual power in an accident situation. It should however be verified that this period is applicable for all plausible situations likely to affect the installation. The probability of core meltdown should thus be able to be significantly limited through sound design choices and compliance with rigorous construction and operating rules.

The compactness of SMRs leads to limiting the size of components, some of which are particularly important for safety, which makes it easier to control manufacturing quality. The feasibility of examination in manufacturing and in operation for certain components of complex geometry (integrated design of certain components) could require the development of suitable verification and inspection means.

Light water designs can benefit from the advancement of knowledge in severe accident phenomenology and can be designed in such a way as to allow in-vessel retention in the event of core melt. This significantly reduces the risk of containment failure. In addition, compact pressurized light water designs have metallic containment (limited leakage rate compared to concrete enclosures) immersed in pools filled with water; this water constitutes in a way a 4th “containment barrier”. The thermal power output of the containment is carried out passively, without the need for a heat sink. The compactness of the design makes it possible to inert the containment to limit the risk of hydrogen explosion in the event of a core meltdown. All these features facilitate the management of core melt situations. The associated releases should be significantly lower than those estimated for a high power reactor.

Finally, compactness makes it possible to consider underground or semi-underground installations, giving the design greater robustness than high-power reactors with regard to certain types of hazards (earthquake, aircraft crash, extreme weather conditions, etc.).

Technological options to be consolidated and safety performance to be verified

For some designs, technological options will have to be consolidated before considering their construction, particularly for innovative components.

Likewise, regarding new designs, in particular those involving passive safety systems, the safety demonstration will require carrying out experiments on representative models. The demonstration of intrinsic safety characteristics will also need a detailed understanding of the physical phenomena involved. This may take more or less time to acquire depending on the technologies and their level of maturity.

Finally, attention should be paid to a potentially increased use of equipment available "off the shelf" which may not have been designed according to the rules and standards required in the nuclear field. Nevertheless, factory production is likely to ensure a level of quality higher than that expected with on-site construction.

Summary

With the information available to IRSN, SMRs should be able to meet more demanding safety objectives than high power reactors in terms of radioactive release in normal and accident situations, including severe accidents, and for core melt frequency. About seventy SMR designs are being developed around the world, but the majority of them remain at the stage of a preliminary detailed project, few nuclear operators having expressed their intention to acquire these types of reactor.

A smaller quantity of radioactive material, the possible use of a wider choice of design options, the possible simplification of the design to meet the safety requirements in force and the enhancement of inherent safety characteristics are all features that can be used by designers. However, the implementation of innovative systems is an aspect not to be neglected, and the expectations of the safety authorities in terms of demonstration will require the use of experimental platforms.

The factory production of all or part of the reactor modules should make it possible to ensure an increased quality of manufacturing, compared to a more traditional method of construction.

Nevertheless, the characteristics of the designs will have to be examined in detail in order to be able to position oneself further on the actual level of safety that can be achieved by these types of reactor.