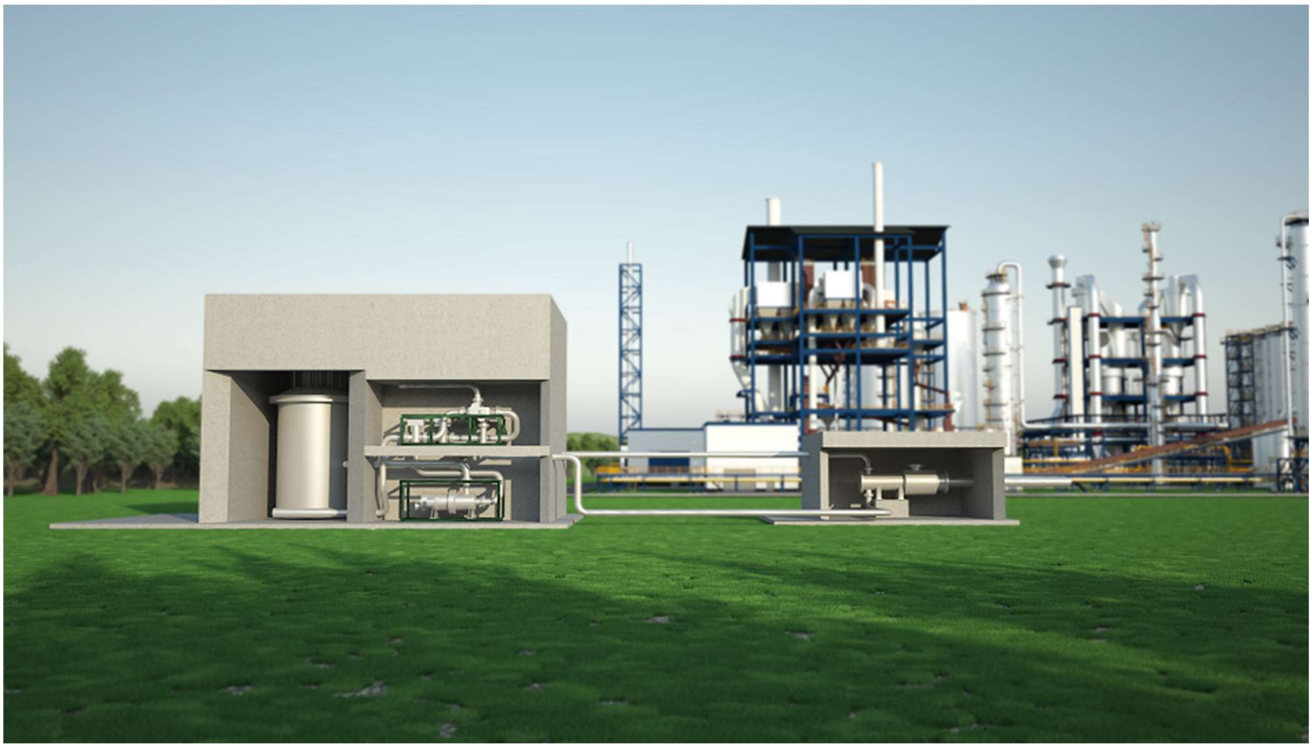
IMIA WORKING GROUP WGP 132 (23)
RISKS ASSOCIATED WITH RECENT DEVELOPMENTS IN NUCLEAR POWER
SMALL MODULAR REACTORS



Source: JIMMY ENERGY general arrangement of the 10 MWth reactor

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APPENDIX

EXECUTIVE SUMMARY

Our work aims to link the technology to the insurance part of an SMR and anticipate underwriting methods and solutions to guarantee conventional and nuclear risks for these technologies. Three parts are studied, the different technical aspects with classification of the SMRs, the legal aspects and liability which are driving the nuclear word and the insurances in particular the applicability of the current nuclear third party liability Paris and Vienna conventions , the impact of the technologies on the transportation insurance liability, and finally an associated insurance study, indicating the different risks and perils, with the options allowing Insurers to respond to manufacturers/operators with smooth solutions.

In the technical part, after reviewing the main types of SMR in the SMR typologies & classification, we review the safety aspects, the uses in the industry and, establishes a comparison of time schedules between big nuclear power plant construction and SMR version.

We will give also some examples of different types of design proposed today, emphasizing those that are already in advance developement. We will point out the limits of each proposal, the management of the risk of proliferation for very small reactors, the limited interest for "large modular reactors" which will undergo or are likely to quickly undergo the vagaries of the large ones, by switching to a construction problem (Civil Works, project size, site costs control etc…).

After having discussed the passive safety features due to their design, we will establish a matrix of the use of SMRs, electricity, heat, cogeneration and industrial processes, the impacts on the activities of the industrial areas, and the risk from the environment on the concerned SMR.

Concerning the legal aspects, the impact of the decision to load nuclear fuel in the workshop is significant. Although factory fuelled SMRs might only concern microreactors such as towed barges, they imply important modifications of the timetable for the legal implementation of nuclear liability risk insurance. The need and interest to have a project framework including construction activities for a nuclear operator could promote the implementation of policies that meet the criteria of the conventions (Paris and Vienna Conventions) between subsequent operators. The person putting the fuel in reactor will have a nuclear operator status, and the factory should be an nuclear installation.

In the Underwriting consideration chapter, we will study the possible consequences of factory fueling, activated or not and depending on insurance approaches. The Insurance part deals with the novelties caused by the techniques implemented on this type of nuclear power plant. We explain the new limits and frontiers between the conventional property cover and the intervention of nuclear risk insurance products, depending on the moment of changeover from conventional construction to nuclear insurance.

Furthermore, the resurgence of risks related to natural perils should be pointed out, as the SMR may be intended to be positioned in isolated regions (for example, to compensate for a lack of energy power). The sites will therefore not be, as for the large units, mainly defined according to the low exposure or the relative mildness of the natural events but by the location where energy will be needed (for example in large industrial or nearby populated areas).

The human and economic environment in which the SMRs will be established will also have a significant impact in terms of insurance and the cost of compensation to be provided.

Our last part will also consider underwriting issues, the specific risks introduced by SMRs and their design, their production in the factory, the effects of series, the monitoring of accumulations and the scenarios leading to the calculation of the MPL indicated in the matrix in the Appendix. The structure of the insurance contracts will also be studied.

ACKNOWLEDGMENTS & DISCLAMER

Thanks to; Jimmy Energy, Westinghouse Electric Company, SFEN and acknowledgement for free using of Constructors explanation & information about SMRs, Rosatom, CGN, CNNC, CNEA, CANDU, SPIC, EDF Consortium, Hitachi GE, KAERI KA CARE,OKBM, NIKIET, NRC, NuScale, Holtec, BWX, JSC OKMB, Tsinghua University, SINAP Rolls Royce, but also, EDF, WNA, IAEA ,NEA, IMIA in particular documents below in references.

We would like also to acknowledge and thank all the people who worked on the document, answering our questions and allowing participants to get a better view of the systems.

With thanks for the free using of pictures, documents and references which gave a better view of the subject to participants.

Credit must be given to all the literature existing on subject which can be read on the internet, and in paper documents (especially the pictures, descriptions of systems and schemes to understand) and which shows the extent of progress the industry in general has made, in particular engineering firms, engineers, controllers and also other specialists, for their commitment to upgrade levels of safety. The document established is done for the improvement of the knowledge and promote the best practices in insurance. There is no other intention from the participants.

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INTRODUCTION

Today, several countries are working on the design of small modular reactors (SMRs) with a power below 300 MWe. The design and integration of these devices is not new if we consider the evolution of the propulsion of submarines in history and later that of the icebreakers of the Far North.

Regarding electricity production, for several decades, the power of reactors has continued to increase. This power increase was intended to achieve economies of scale, reduce the cost per kW(e) installed and therefore reduce the cost per kW produced. As a result, the unit powers have passed the 600MW, 900MW, 1300MW, then 1700MW levels for the Flamanville EPR and up to 1760MW for the Taishan EPR, the 2 units of which were commissioned in 2018 and 2019 in the province of Guangdong in China. This race for gigantism has recently shown its limits in the reduction of achievable costs per kWe). Many reasons that we will not develop in this document are responsible for these adverse developments that are due to a combination of several factors, among which; the loss of knowledge in the "Nuclear Industry" in European countries and the increase in demands for security systems following the latest accidents (in particular that of Fukushima Daichi in Japan). These adverse developments are worsened by a context where renewable energies develop to the detriment of fossil energies such as coal and, unfortunately, nuclear energy (*read among others, the report of the "*Cour Des Comptes Française" on the costs of the nuclear industry*). All this together constitutes an environment where nuclear power, despite its share of approximately 10% of world electricity production, has difficulty in being considered as a safe, reliable and clean source of energy.

Several countries have been no longer interested in the scale effects related to giant installation., which still remain an avenue for some, but in the potential gains linked to the industrialization of an SMR concept. For nuclear power, the implementation of a modularized industrial plan could make it possible to obtain the expected effect and return to more reasonable investment and therefore production costs in a mixed energy system. Based on what exists for other industries, such as offshore petrochemicals, or even gas turbines for electricity production in certain environments, (such as weakly meshed grids in countries with low consumption), the concept of the modular nuclear power plant appeared. Indeed, in petrochemicals, the construction via a step of sub-modules of identical templates manufactured in the factory and assembled in the ports has made it possible to produce giant, towable platforms, and to considerably reduce costs while adapting the product to its environment.

According to this concept, a product, licensed, manufactured in the workshop individually, small enough to control all the components assembled in the factory, which can be installed in modules and in sets up to several units if the nominal power requires it and including mostly passive security systems, therefore very safe, should make it possible to considerably reduce costs, on the condition that orders reach a threshold number defined in advance. This is the principle of SMRs.

Thanks to their low power due to size reduction, certain reactors can meet these criteria and avoid the disadvantages and trial and error of high-power series heads. While an EPR 1 costs far more than a common GEN II PWR unit (see Cour Des Comptes report 2012 evaluation) depending on the parameters taken into account, this new technology should allow access to nuclear energy for first-time buyers in Southeast Asia, the Middle East, South America and Africa. It will also meet the needs of countries whose network is poorly meshed, such as Canada, but also the United States, where grids are mainly of the "tree type" with few interconnections, unlike Europe where the countries are very connected. There is also a large market, in the years to come, to replace the old, very polluting coal-fired power stations, built before 1976, and whose power is often between 300 and 400 Mwe.

We can easily understand that with the introduction of factory-fuelled SMRs, the current boundaries between conventional and nuclear insurance will be altered. Indeed, to date while the conventional side includes all the manufacture of reactor elements, the tank, pumps, steam generators, and other boosters, their transport, the construction of the concrete foundation elements which accommodates them, the metal assemblies on site, the welding (with difficulties of carrying out heat treatments for large pieces of piping), nuclear insurance only intervenes when the fuel elements arrive on site to cover the consequences of assembly and commissioning and continues with the cover of operational risks.

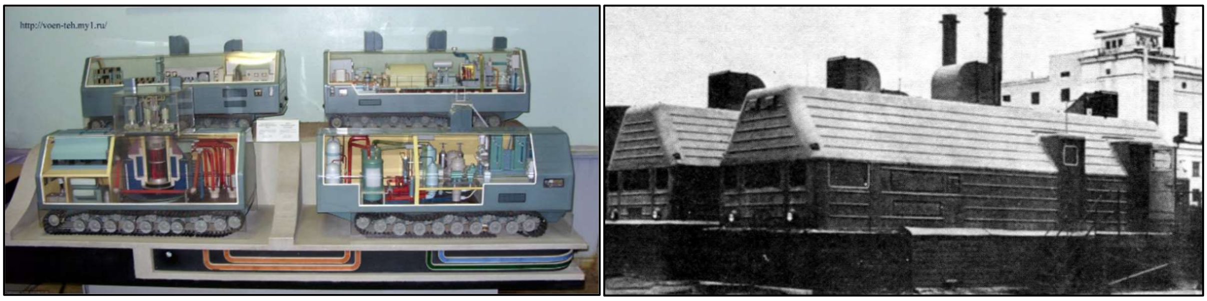
For an SMR a certain number of construction constraints will disappear. The world of nuclear insurance, based on the analysis of the Paris, Vienna and Brussels Conventions, must respond to this new concept and be able in the years to come to offer a nuclear insurance solution that meets the specific needs of this product as part of its industrial sector. This response must include the notion of nuclear operator liability coverage from the assembly in the workshop, nuclear material transport liability, conventional assembly of parts already considered to be sources of ionizing radiation and finally the operation liability, but also damage insurance, whether for construction or the start of operation.

After having reviewed the different types of SMR, and having compared certain phases of the projects with those of a traditional high-power nuclear power plant, reviewed the safety and security concepts which stay mandatory for SMRs, we will try to review the modifications giving rise to new interactions of the different categories of insurance coverage. In particular the impact of the usual nuclear exclusion clauses, and their ability to answer to the needs of SMRs as well as the influence of the chosen SMRs technologies on the positioning over time of insurance will be explored. The influence of changes in project schedules resulting from the chosen technology will be discussed as well.

1. MAIN TECHNOLOGIES

1.1. HISTORICAL BACKGROUND

As early as 1958, the Russians developed a small and mobile nuclear reactor. The TES3 was a 1.5 MWe reactor whose modules were mounted on enlarged tank chassis. It was intended to produce electricity in difficult-to-access areas, such as the Kamchatka peninsula and the far north of Siberia. It was used from 1961 to 1964.



Obninsk Nuclear Museum, cited in "La technologie des réacteurs à eau pressurisée" p38, Serge Marguet, EDP Sciences Editions, 2019.See also https://nuclear-power-engineering.ru/en/article/2022/01/14/

The concept of SMRs is therefore not new, but it is in the naval field that the concept did develop the most.

At the instigation of Admiral H. Rickhover, the Americans were the first to equip a submarine, the Nautilus, with a small nuclear reactor. Thanks to a considerably increased autonomy, she carried out her first mission under the ice pack in 1958. The Russians quickly followed and in 1962, the K-3 Leninski Komsomol reached the North Pole under the ice. In the context of the Cold War, an arms race started. Between 1955 and 1991, Americans, Soviets, British and French built a total of about 400 nuclear-powered submarines. China and India commissioned their first nuclear-powered submarines in 1974 and 2009 respectively.

On-board nuclear reactors are also used on surface ships, such as American aircraft carriers and several Soviet battle cruisers. Nuclear propulsion also has some civilian applications, notably for some Russian icebreakers.
Finally, in 2019, the Russians developed the first floating nuclear power plant, the Akademik Lomonosov, which they are deploying to power the new resource exploitation sites in the far north of Siberia that have become accessible via the Arctic Seaway. This unit might foreshadow the future of SMRs.

In the context of climate change, nuclear energy is an option of interest because of its low carbon footprint.

However, access to nuclear technologies remains difficult for most countries. Indeed, it requires very significant investments, not only regarding finances (the construction of a nuclear power plant requires huge initial investments) but also when considering scientific efforts (R&D), human resources (highly qualified engineers and technicians must be trained), industry (a solid industrial base is needed to ensure construction, operation and maintenance of NPP, as well as to build a suitable electricity distribution network), and even administrative organization (capable and independent regulatory authorities are needed).

As a matter of facts, only most developed countries have a nuclear power industry: the United States, Canada, Russia, China, France, Great Britain, Germany, Korea, Japan, etc…

To allow other mid power countries to join the nuclear club, the idea emerged to develop smaller modular reactors, requiring a lower overall investment, the ultimate objective being to bring them to replace their old gas or coal power plants with new nuclear units of equivalent power.

1.2. DEFINITION OF A SMR

There is no agreed definition. However, main characteristics of SMRs and their associated issues can be identified.

Small

An SMR is a small unit, i.e. a low power unit compared to existing first or second generation reactors, which are generally in the range of 2000 to 3000 MWth. The targeted power for SMRs is rather of a few tens to a few hundreds of MWth.

This reduced power allows different design options: compact reactors with fewer auxiliary circuits (the steam generators can be integrated, for example), use of natural circulation instead of primary pumps, etc. The residual shutdown heat is also lower, which makes it possible to rely only on natural convection to cool the core. Overall, SMRs use simpler architectures and are based on passive safety concepts.

The low power also allows for smaller operating and maintenance teams on site. This makes it possible to offer complete services similar to Build Own Operate schemes to countries that do not have the necessary industrial and human resources structures to develop nuclear energy.

Modular

An SMR is modular. On the one hand, this allows for manufacturing it in the factory and not on the final installation site. On the other hand, it allows for less onsite maintenance. Major maintenance is done by standard module exchange and not by complete onsite disassembly/reassembly. The purchasing country therefore has less industrial effort to make for construction and operation.

In addition, modular construction allows for a greater series effect, to the benefit of the designer/builder.

However, this modular design might induce more complex transit, which would involve not only transportation of nuclear fuel, but also of complete nuclear cores.

Reactor

An SMR remains a <u>nuclear</u> reactor.

As such, it must comply with a constrained legislative and regulatory framework, developed and controlled at the international level by the IAEA (safeguards) and at the national level by the competent authorities. This is due to the sensitivity of nuclear technologies in terms of safety (risk of accident) and security (risk of misuse or proliferation).

Adaptations will be necessary. Although the development of SMRs will, undoubtedly, be feasible, lowering safety and security standards is not an option. Indeed, this would call into question both the social acceptability of SMRs and their economic model (neither the population nor the authorities of target countries will accept a less safe "low cost" nuclear energy). On the contrary, if SMRs want to move closer to urban centres, they will have to demonstrate an even higher level of safety and security than current NPPs.

1.3. SMR TYPOLOGY AND CLASSIFICATION

In the absence of a definition, there is obviously no agreed typology either.

The IAEA's ARIS (Advanced Reactors Information System) database lists some 80 SMRs projects under development. To this number, one must add all the unchartered concepts being developed by new entrants, in particular start-ups, proposing sometimes very innovative ideas. Thus, in total, the number of SMRs projects underway in the world can be estimated at about eighty (approx.), at various stages of progress

These projects can be classified in different ways.

- ✓ **By purpose**
  Apart from research reactors, the current generation of commercial reactors is aimed at producing electricity. SMRs have a much wider range of applications: electricity production, but also heat production, desalination, hydrogen production, transmutation of highly radioactive nuclear wastes, etc.

- ✓ **By power**, being understood that an SMR is globally in the range 5 to 450 MWe.
  One sometimes considers a sub-category, the micro modular reactors (MMR), with a power of less than 10 MWe (about 30 MWth).

- ✓ **By type of technology**
  A distinction can be made here between:
  - o SMRs based on a tried and tested PWR (pressurized water) or BWR (boiling water) technology. These are in fact integrated and compact versions of the current reactors, based on the know-how acquired in the naval field and on the progress made with the third generation. The heavy water reactors (HWR) also enter this category.
  - o Fourth generation SMRs, (called Gen IV)

    These are more innovative reactors, using various fuel/moderator/coolant combinations. In this category, one can find:
    - ↳ High temperature thermal neutron reactors (HTR/VHTR)
      - Helium / graphite (GCR)
      - Molten salts / graphite (MSR)
      - Super critical water (SCWR)[1]
    - ↳ Fast neutron reactors (no moderator)
      - Helium or CO_2 (GFR)
      - Sodium (SFR)
      - Liquid Lead or bismuth/lead (LFR)
      - Molten salts (MSFR)

- ✓ **By state of project development**
  The multiple projects currently underway will not all be completed. A distinction is made between SMRs in the design stage, SMRs with a license, SMRs in the construction stage, and SMRs in operation. In this latter category, as of November 1, 2022, there are only two Russian pressurized water reactors of the KLT-40S type, each with a capacity of 35 MWe, built by ROSATOM and on board the Akademik Lomonosov. [2 & 3]
  Apart from these, the only SMR already licensed is the Korean SMART, a 300 MWe pressurized water reactor. The U.S. Nuscale, also a pressurized water reactor (but with only 77 MWe per unit, several of which can be assembled together), is undergoing licensing review.
  Thus, two categories of SMRs are appearing:
  - o Those based on a proven technology (such as PWR) and using already validated concepts and/or architectures (e.g. integrated steam generator). These SMRs could arrive on the market in a fairly short time (a few years);
  - o Those based, on the contrary, on a technology still under development, for which several successive stages may be necessary: a research reactor (for the validation of the neutronic and hydraulic model), an industrial demonstrator, before arriving at

[1] It should be noted, however, that there are currently no SCWR-type projects with a capacity of less than 1000 MWe. Therefore, they do not really fall into the SMR category.

[2] The Chinese HTR-PM reactor, a 210 MWe high-temperature gas-cooled reactor (following the HTR10 demonstrator built by Tsinghua University), at Shidao Bay, is sometimes classified as an SMR. However, it is not modular nor small.

[3] Similarly, India's IPHWR220, a 220 MWe pressurized heavy water reactor of which 16 units were built, is also sometimes classified as an SMR because of its low power, but it is not truly modular nor small either.

the “First of a Kind”[4]. These SMRs will probably not reach the market before 10 to 15 years.

✓ **By fuel**
The fuel is directly related to the technology chosen. Therefore, it is not a different classification criterion.
However, the fuel issue remains essential:

- The choice of a fuel, its form and its cycle length determine the frequency and the complexity of core reloading and, consequently, the organisation of the reactor life cycles.
- Some SMRs use conventional low-enriched UO2 fuel, for which new fuel fabrication as well as spent fuel reprocessing routes already exist.

But other SMRs aim at using unusual fuels, either in their form (e.g., pebble bed reactor), or in their enrichment (e.g., highly enriched UO2 (HALEU) in order to limit the frequency of fuel reloading), or in their composition (e.g., MOX or other mixture with actinides, notably for fast neutron SMRs).

- These fuels will either require significant development and industrial adaptation of the fuel production line (some of which are even to be created). This will obviously have a significant impact on the operating cost of the concerned SMRs, which could call into question the economic viability of these projects.
- Furthermore, some fuels, because of their enrichment rate or their composition, may present risks from the point of view of the physical safety of the materials. These risks will have to be considered in the design as well as in the organisation of operation.

✓ **By country and designer/builder**
Here, one can consider:

- In countries with a complete nuclear industry:
  (USA, Canada, France, United Kingdom, Japan, South Korea, China, Russia, India)
  - SMRs designed and manufactured by large companies belonging to the existing nuclear industry, which benefit from a proven experience, master the procedures for commissioning a new nuclear unit and have a complete and solid industrial tool.
  - SMRs led by newcomers in the nuclear sector (other energy companies, large industrialists, start-ups, etc.), some of them seeking a technological breakthrough.
- In countries with more limited nuclear experience:
  (Brazil, Argentina, South Africa, Indonesia, UAE, etc.)
  - SMRs carried by local nuclear players, whose experience and solidity vary, but who are capable of innovation.

It is proposed to retain the following classification, distinguishing between thermal and fast neutron reactors, and classifying them from the core temperature by combining several of the above elements.
The coolant outlet temperature determines the secondary temperature, which in turn determines the efficiency (for a conventional Rankine steam cycle), and the possible industrial uses.

[4] In a number of situation, the industrial demonstrator could finally be the “First of a Kind”.

Coolant Temperature	Type	Coolant	Fuel	Moderator	Uses	M (*)
Thermal Neutron						
280-300°C	BWR	Boiling water	Uranium oxide	Light water	- District heating (co-generation) - Power generation	
300-350°C	PWR	Pressurized water	Uranium oxide	Light water	- Desalination - Power generation	
	HWR	Pressurized heavy water	Uranium naturel	Heavy water	- Power generation	(1)
374-550°C	SCWR	Supercritical water	Uranium oxide Or Thorium oxide and Plutonium	Light water	- Power generation - Other miscellaneous industrial uses (pulp and paper, hydrocarbon refining, methanol production, etc.)	
550-700°C	MSR	Molten slats *(Fuel is thinned in the molten salt which, in a liquid form, is the coolant itself)*	Various mixture of salts of [uranium or thorium] and [sodium chloride or lithium fluoride or beryllium fluoride for example], in a liquid state	Graphite	- Power generation - Hydrogen production by methane reforming	
700-1 000°C	GCR (HTR)	Helium	Enriched uranium oxide in the form of a pebble bed or Uranium oxycarbide in the form of TRISO (tri-isotopic microparticles) included in the core structure itself	Graphite	- Hydrogen production, either by reforming methane, or by gasification of coal (coal gas), or by thermal dissociation of water. - Metallurgy	(2)
Note 1: For all the above categories using UO2, the enrichment rate often reaches 8 to 10% in order to limit core reloading.						

Coolant Temperature	Type	Coolant	Fuel	Moderator	Uses	M (*)
Fast Neutron						
350-750°C	SFR	Liquid Sodium	MOX U-Zr ou U-Pu-Zr		- Power generation - Other miscellaneous industrial uses (pulp and paper, hydrocarbon refining, methanol production, etc.)	(3)
	LFR	Liquid metal (lead or lead/bismuth)	HE UO_2 MOX PuN–UN (nitride)			
550-700°C	MSFR	Molten slats *(Fuel is thinned in the molten salt which, in a liquid form, is the coolant itself)*	Various mixture of salts of [uranium or thorium] and [sodium chloride or lithium fluoride or beryllium fluoride for example], in a liquid state		- Power generation - Hydrogen production by methane reformation	
700-1 000°C	GFR (HTR)	Helium CO2	MOX Uranium oxycarbide		- Hydrogen production, either by reforming methane, by gasification of coal (coal gas) or by thermal dissociation of water. - Metallurgy	
Note 2: The fuels used in FNR are usually either highly enriched or contain Pu, sometimes at high level.						
(*) The "M" column assesses the maturity of the technology. In green are proven technologies. In orange (+/- dark) are technologies under development. (1) India is operating IPHWR 220 reactors. (2) China is completing the commissioning of the HTR-PM reactor (industrial demonstrator). (3) The SFR technology was already tested in France, including on an industrial scale (Phénix, Superphénix), but it was abandoned. Russia has also developed the technology and operates the BN600 and BN800 reactors. It is building a BN1200 reactor. China has developed an industrial demonstrator (CEFR), which has been in operation since 2014. Finally, India also has an industrial demonstrator (FTBR).						

Many concepts related to these different technologies have been tested to varying degrees in research reactors around the world since the 1950s and 1960s. But few have reached the industrialisation stage. Among them, however, the followings should be noted

(1) India is operating IPHWR 220 reactors.
(2) China is completing the commissioning of the HTR-PM reactor (industrial demonstrator).
(3) The SFR technology was already tested in France, including on an industrial scale (Phénix, Superphénix), but it was abandoned. Russia has also developed the technology and operates the BN600 and BN800 reactors. It is building a BN1200 reactor. China has developed an industrial demonstrator (CEFR), which has been in operation since 2014. Finally, India also has an industrial demonstrator (FTBR).

In addition to this table, there are subcritical reactor projects, such as that of the Swiss company TRANSMUTEX, which aims to use a proton particle accelerator to generate, after spallation, an intense neutron flux to produce energy from thorium, as well as to burn long-lived radioactive waste.

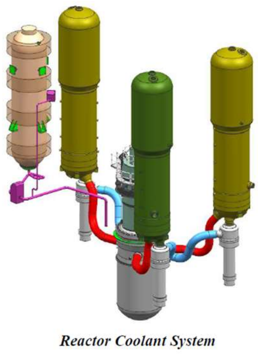
1.4. TECHNICAL DESCRIPTIONS (EXAMPLES)

Several major milestones have been reached in SMR technology deployment. The Akademik Lomonosov floating power unit in the Russian Federation with two-module KLT-40S was connected to the grid in December 2019 and started commercial operation in May 2020. The HTR-PM demonstrator in China was connected to the grid in December 2021 and is expected to reach quickly full power operation. The construction of ACP100 in China started in July 2021 and is targeted to start commercial operation by the end of 2026. The construction of BREST-OD-300 in Russian Federation began in June 2021 and is planned to be completed in 2026. In Canada the construction of a GE-Hitachi BWRX-300 has been launched in 2023 at Ontario Power Generation Darlington plant, for completion in 2028.

Among the most advanced projects, we will name below without any order, classified by country of origin some different kind of SMRs.

1.4.1. UK version

The **Rolls-Royce** SMR has been developed to deliver a market driven, affordable, low carbon, energy generation capability. The developed design is based on optimised and enhanced use of proven technologies that presents a class leading safety outlook and attractive market offering with minimum regulatory risk. It is primarily intended to supply baseload electricity for both coastal and inland siting.
The SMR is a close-coupled three-loop Pressurised Water Reactor of 470Mwe employing an indirect Rankine cycle. The nuclear fuel is industry standard UO2 enriched up to 4.95%.



Credits: Rolls Royce SMR ™ Description Oct 2022

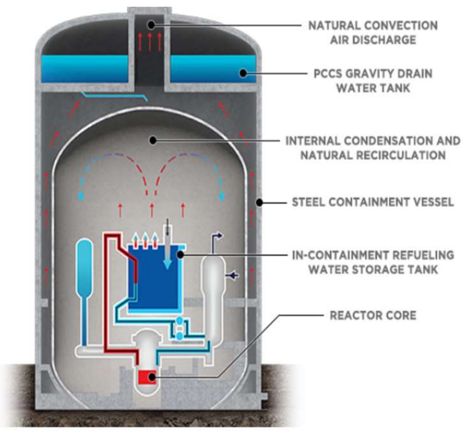
The Rolls-Royce SMR entered formal design assessment by UK regulators in 2022 and targets completion in time for construction of the first of a kind power station to commence in 2026.

1.4.2. USA solutions

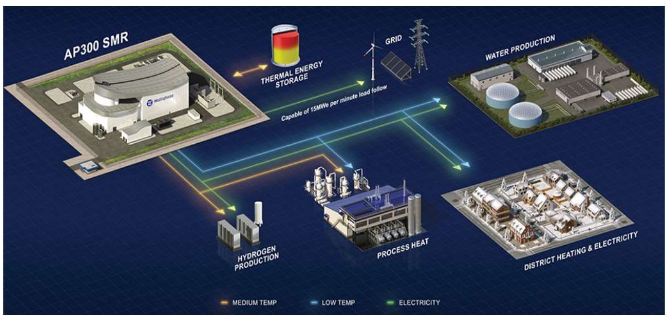
USA is proposing different kinds of SMRs ranging from micro to big PWRs which allow a full replacement of coal fired power plant with same NPP power range. Among them are identified,

- ✓ The SMRs of several kind from Westinghouse such **AP 300** issued from AP1000 design and the **eVinci** TM as micro SMR,
- ✓ the **NUSCALE$_{TM}$** type,
- ✓ the **BWRX-300** from GE-Hitachi,
- ✓ and the 160 MWe one from **Holtec**.

NUSCALE$_{TM}$ is one of the most advanced projects which has obtained certification from the American Safety Authority NRC in August 2020. It is a 76 MWe unit, whose reactor operates in natural circulation (no primary pumps), with a cooling system and passive safety assemblies. Currently a first project of 12 modules is being discussed with “Idaho National Laboratories”. The project could be completed between 2023 and 2029 for the first 2 reactors, with start-up in 2030. The cost price would be approximately USD 4,200 /kWe.
A certain number of countries would be interested in this technique allowing to considerably simplify all the circuits necessary for the good functioning of a reactor, (passive circuits) we will quote, the United States, Canada, Great Britain, Jordan, Romania, and more recently, Poland.
From Westinghouse the **AP 300** of 900 MW th is designed with one loop, with passive safety systems reducing the needs of backup power and water supply. The uses envisaged are of course linked to the supply of electricity, but also the production of Hydrogen, district heating, water production and process heat .



AP 300 view credit: Westinghouse



AP 300 application versatility, credit Westinghouse

GE Hitachi **BWRX-300** is a 300 MWe water-cooled, natural circulation Small Modular Reactor (SMR) with passive safety systems that leverages the design and licensing basis of GEH's U.S. NRC-certified ESBWR.

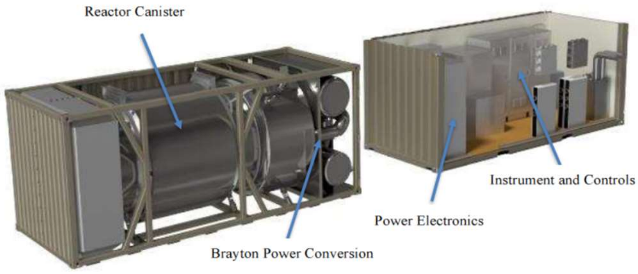
Simplified design :

- Estimated 50% less construction material per MW as compared to large reactors
- Passive cooling and natural circulation – increased safety of design
- Elimination of unnecessary systems – fewer components needed

Simplified execution :

- Innovative construction techniques, modularization - reduces on-site work
- Vertical shaft construction - eliminates as much as one million cubic yards of excavation

The **SMR-160** from (Holtec Nuclear) with a power of 160 MWe, also operating with a natural circulation boiler and whose prototype could be built on the Oyster Creek site (USA). The countries interested are, the United States, Ukraine which would consider the installation of the head of series and an assembly plant on its territory.
Among the micro reactors we identified the **eVinci** ™ from Westinghouse Electric Company LLC. The Westinghouse **eVinci** ™ Micro Reactor is designed for energy generation in remote or isolated locations. The design can produce both process heat and electricity for remote communities, mining operations, or critical infrastructure installations. The key attribute of the design is its transportability within standard shipping containers. The design is based on heat-pipe reactor technology that has been developed and tested by Los Alamos National Laboratory for space applications. Because of its compact and simplified design, the **eVinci** ™ Micro Reactor will be manufactured and fuelled in a factory, and then transported to an end user site. eVinci reactor and power conversion system can be packaged into two standard transport containers. One of the containers houses the reactor and the power conversion system. The other container includes power electronics and the instrumentation & controls (I&C) system.



***eVinci** ™ micro reactor schematic, credit Westinghouse*

The fundamental reactor design is based on a solid core block that includes a matrix of nuclear fuel, moderator and heat pipes that extract the heat from the core region. The reactor core by itself is subcritical. It requires radial and axial reflectors to improve neutron utilization. Reactivity control and shutdown are performed with radial control drums placed around the core. Shutdown can also be performed with shutdown rods that can be inserted into the core block.

1.4.3. Russian alternatives

Studies of Russian origin such as the Akademic Lomonosov “barge” plant of the **KLT 40 S** type, and its land version **RITM-200** respectively under operation and nearly to be achieved. The technique comes from that used by Russian icebreakers, and therefore widely tested. The first one has been operating in Siberia since 2019, and thanks to its power of 2X35 MWe, has enabled the dismantling of an aging and polluting coal-fired power plant, as well as the gradual shutdown of the 4X12MWe Bilibino nuclear power plant, which has become difficult to maintain considering the techniques implemented at the time of its construction for the realization of its foundations. We agree here on the interest of this type of SMR allowing to quickly meet the needs of industrials and the population in safer conditions while reducing pollution. The cost of the barge would be around USD 340 M$, which gives USD 4,200 /kWe. A more powerful version of 110MWe consisting of 2 reactors of the RITM 200 type of 55MWe which equips the new Russian icebreakers is under study for 2025.

The VBER 300 currently available as a naval unit, but which can be used on land is planned for 2030. Again, on barge, the power supplied would be 650 MWe with 2 units on the same development as the previous barges.

1.4.4. Chinese designs

CHINA with, among others, the **ACPR 50** which is a 60 MWe PWR (REP) designed by CGN subsidiaries.

As with Russia, China is interested in maritime-based designs, for flexible use, which can allow travel. A barge variant is under construction. One of China's major export markets is the developing countries. Consequently, in this logic, the developers are interested in a low-cost product, allowing electricity to be quickly accessible, flexible, being able to be satisfied with a tree-type grid and little mesh, as one can find in certain countries of Africa or Asia. Equipment on barges can, subject to local and international legal authorizations (navigation), be easily replaced if necessary.
The ACP100 called "**Linglong One**" which is also a 125 MWe PWR made by CNCC, also with passive safety systems. The 1st is under construction at the Changjiang power plant, it will be operational around 2025. China with this equipment is aiming for land use, particularly in the mining sector.
The following units, such as the **HTR-PM**, which is still a technological demonstrator operating on high-temperature gas, and the 105 MWe **HTGR** produced by CNNC, seem more difficult to sell for export based on unique use (replacement of coal fired power plant boilers) and with criteria easily accepted by the public.

2 units went into operation in May 2021 in Shidao-bay for an estimated cost of around USD 1 billion. The unit is made up of two associated reactors to power a 210 MWe steam turbine. The water-steam cycle of the secondary circuit is that of a standard coal-fired power plant.

A Project of 6 units could follow allowing to reach an investment price of USD 3,000 /KWe. It could eventually replace coal-fired power plants in China for electricity production.

Credit: CNNC
Similarly, Chinese CGN engineers are also developing the 70 MWe **NHR -200**-II. CNNC's **DHR-400** is also under study for a unit power of 135 MWe as well as the **HAPPY 200** of 70 MWe. Both are PWRs for heating networks in northern China, again to replace aging coal-fired power plants. The start of construction of the first units is scheduled for 2022 or 2023.

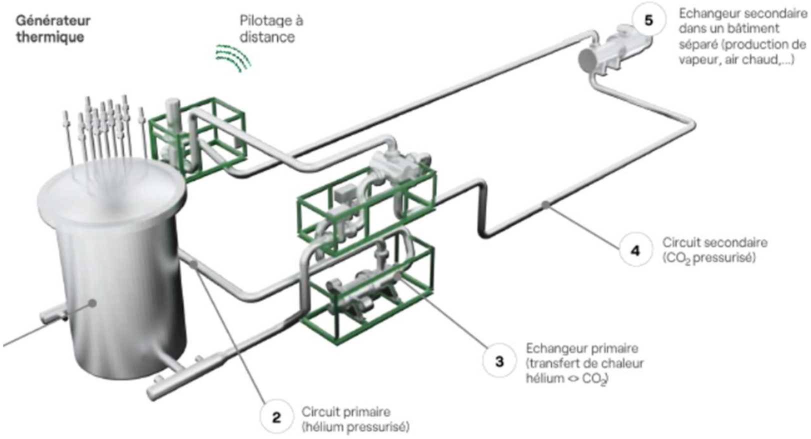
1.4.5. French types

Different types are proposed, and the French Government is pushing to increase the development of solutions. Among them The French version of the PWR modular reactor is proposed by the **Nuward** $_{TM}$ project. It is a joint project between EDF, CEA, NAVAL GROUP and TA, which recently entered the APS phase (summary preliminary project) at EDF and which remains open to possible international cooperation. It is a PWR, whose basic module consists of 2 very compact reactors of 170 MWe each in the same building. The assembly is available in sub-modules, the sizes of which are those of 20-foot containers for transport to the equipment operating site and of "orange wedges" assembled on the final site for the nuclear boiler room.

All sub-modules are assembled and built in the factory, for a total duration of manufacture and final assembly on the destination site of 36 months. Among the innovations to achieve this concentration, we note plate steam generators, factory-integrated in the tank, passive cooling systems made possible thanks to the limited size of the device, a metal enclosure immersed in a pool of water in a semi-underground building, the size of which ensures, without an additional water reserve, a cooling period of 7 days when shut down. and makes it possible to dispense with emergency Diesels. The first units should be operational in 2030. A demonstrator will be set up in France, but the target market is definitely export, for the same reasons as indicated above. Countries such as Jordan, Brazil and Canada have shown their interest.
Another one is a micro-reactor which is dedicated to the industry sector to decarbonize production. **JIMMY Energy** propose a high-temperature gas-cooled micro reactor of 10 MWth. The reactor is based on UCO TRISO particles, a graphite moderator and a helium coolant. A CO2 secondary loop allows delivery of heat up to 550°C for industrial processes. The approach consists in delivering a simple, safe and robust heat generator. As a result, the design relies mostly on well-tested solutions, as well on a passive safety demonstration, to

optimize the time- and cost-to-market. The first system will be available in 2026, with a first client site already identified. The primary target is the French market, especially steam-consumers such as the Agro or Chemical industry, with needs for steam up to 550°C. After massive deployment to process heat applications in and outside of France, the main applications are district heating (offices, residential buildings...) and hydrogen production.

The use of a secondary CO2 loop allows to distinctly separate the nuclear perimeter from the industrial zone in terms of safety. The definition of the nuclear zone (HRZ) for insurance purpose is clear, and the cold (conventional zone) also. Furthermore, the manufacturing and assembly aspects have been considered since the beginning of the detailed design: design teams are in contact with presented suppliers to screen commercially available components and integrate them in the design. It ensures that a viable industrial scheme is available and to anticipate the orders of long-lead items, as well as to optimize instruction time by safety authorities.



Credits: JIMMY Energy Description 2023

The JIMMY Energy solution is based on proven technology.

1.4.6. Canadian SMRs

The **CANDU® Small Modular Reactor** (SMR) of 300Mwe is being developed as a proven and mature design to help countries reach their goal of Net Zero. Built on proven CANDU® technology to be quickly deployable, this 300 MW(e) reactor features simplified systems, fewer components, and a modular design. The design objectives are a low-cost, low-carbon power with a high-capacity factor in a compact layout. The CANDU SMR is using natural uranium fuel from fuel manufacturers and avoiding the need to import enriched uranium fuel. The CSMR is based on a decades-long proven design that is licensed in many countries operating CANDU reactors. It meets modern regulatory requirements, with dedicated post-Fukushima features.

The Canadians are also designing the IMSR (Integrated Molten Salt reactor) which is a 192 MWe fluoride molten salt reactor. The concept is based on a reactor loaded with fuel for 7 years of operation, with on-line standard exchange on site. Construction of the first units is expected at the Chalk River site around 2026. Interested countries could be Canada and the USA. This development therefore provides for a unit allowing a total change of boiler room.

Canada is also working on the 14 MWe **HTGR** type micro reactor (**StarCore**) operating on high temperature gas and the 10 MWe **MMR 5** (Global First Power). Both are intended for the mining industry and isolated communities in Canada. With the displacement of the fuel loaded in the factory and whose core could be the transport container, we can see here all the interest of this technique on the reduction of the tasks carried out on the site and therefore the reduction of the complexity of the installations necessary in maintenance. A certification process is underway for the MMR.

1.4.7. Korean solution

The System-integrated modular advanced reactor (**SMART**) from Korean developers, is an integral PWR with a rated electrical power of 107 MW(e) from 365 MW(t). SMART adopts advanced design features to enhance safety, reliability and economics. The advanced design features and technologies were verified and validated during the standard design approval review. To enhance safety and reliability, the design configuration incorporates inherent safety features and passive safety systems. The SMART is a multi-purpose reactor for electric power generation, desalination, district heating, and process heat for industries. SMART has been developed to be suitable for small or isolated grids. The SMART design adopts an integrated primary system, modularization and advanced passive safety systems to improve the safety, reliability and economics. SMART NPP has been designed to have a seawater intake structure and other buildings including chlorination building in the yard. Power block accommodates reactor containment and auxiliary buildings (RCAB), turbine generator buildings and one compound building shared by two units of SMART. Korea Atomic Energy Research Institute (KAERI) received the standard design approval for SMART from the Korean Nuclear Safety and Security Commission (NSSC) in July 2012. A safety enhancement program to adopt passive safety system in SMART began in March 2012, and the testing and verification of the PRHRS and PSIS were completed in the end of 2015. In September 2015, a pre-project engineering (PPE) agreement was signed between the Republic of Korea and the Kingdom of Saudi Arabia for deployment of SMART. This PPE project was successfully completed in February 2019. In 2019, Korea Hydro & Nuclear Power Co., Ltd. (KHNP)/KAERI/K.A.CARE co-applied for standard design approval of the PPE design and First-of-a-Kind (FOAK) plant construction in Saudi Arabia will follow in due course.

1.4.8. Summary

As we see, all the projects constitute a collection of technologies that must be clarified. Some are real advanced developments that can lead to industrialization in the short term, others are promising techniques that have yet to be developed over an average period of 10 to 15 years.

The pipeline of SMRs has the potential to support a variety of energy policy priorities, including decarbonization of electricity as well as decarbonization of new applications where large-scale nuclear and variable renewables may have limitations. In many cases, SMRs would be a game-changer to reach net zero in different regions and settings.

The Nuclear Energy Agency (NEA) established an SMR Dashboard5 looks beyond technology readiness level (TRL) and assesses progress across six additional enabling conditions which are: licensing readiness, siting, financing, supply chain, engagement, and fuel. In each area, the NEA defines objective criteria that reflect substantial progress towards first-of-a-kind (FOAK) deployment and commercialization.

1.5. SAFETY AND SECURITY

1.5.1. Reminder of the general principles of nuclear safety

The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.

The safety standards establish by IAEA [ref: Fundamental safety principles n° SF-1] relies on the following.
10 principles:

- ✓ An effective legal and governmental **framework for safety**, including an independent regulatory body, must be established and sustained.

[5] See the publication *Nuclear Energy Agency OCDE 2023 "The NEA Small Modular Reactor Dashboard"*

- ✓ The prime responsibility for safety must rest with the **person or organization responsible** for facilities and activities that give rise to radiation risks (*i.e. the licensee operating the installation*)
- ✓ **Effective leadership and management for safety** must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks.
- ✓ Facilities and activities that give rise to radiation risks must **yield an overall benefit**.
- ✓ **Protection** must be optimized to provide the **highest level of safety that can reasonably be achieved**.
- ✓ Measures for controlling radiation risks must ensure that **no individual bears an unacceptable risk of harm**.
- ✓ **People and the environment**, present and future, must be protected against radiation risks.
- ✓ Protective actions to reduce existing or unregulated radiation risks must be **justified and optimized**.
- ✓ Arrangements must be made for **emergency preparedness** and response for nuclear or radiation incidents.

Besides, the IAEA SAFETY STANDARDS SERIES No. SSR-2/1 (Rev. 1 - 2016) establishes safety requirements for the design of nuclear plants.
Among those requirements, 3 fundamental safety functions and a basic concept arise.
The 3 basic safety functions to be maintained at all time are:

- **Control over reactivity**
  It determines the capability to safely shut down the reactor and maintain it in a safe shutdown during and after all appropriate operational states, as well as in accidental conditions. It is globally the ability, in all conditions, to keep control over the number of fission reactions in the core and make sure the reaction chain will remain under control. It relies notably on a reliable neutron flux detection system, normal mechanisms to regulate the neutron flux in operation, and emergency safety systems able to promptly stop the chain reaction in case of any incident.

- **Confinement of radioactive materials**
  It determines the capability to reduce the potential for radioactive material release and to ensure that any release is within prescribed limits during and after operational states, as well as within acceptable limits during and after design basis accidents. It relies on a series of barriers to maintain radioactive materials in the nuclear unit. For instance, in Gen II or III PWR, following barriers are usually considered: the fuel cladding, the primary circuit, and the containment vessel.

- **Heat Removal**
  It determines the capability to remove residual heat from the reactor core during and after operational states, after shutdown, as well as in accidental conditions. It is globally the ability, in all conditions, to extract the heat produced in the core to avoid any risk of local meltdown. It can rely on various systems, active and/or passive, to be used in normal and/or emergency situation. Unless it is proved that natural convection is sufficient, it requires the permanent availability of a heat sink.
  Paragraph 3.31 of the Fundamental Safety Principles n° SF-1 states that: "**Defence in depth** is implemented primarily through the **combination of a number of consecutive and independent levels of protection** that would have to fail before harmful effects could be caused to people or to the environment." There are **five levels** of defence.
  A relevant aspect of the implementation of defence in depth for a nuclear power plant is the provision in the design of a series of physical barriers, as well as a combination

of active, passive and inherent safety features that contribute to the effectiveness of the physical barriers in confining radioactive material at specified locations.
The independence of the different levels of defence is paramount.
Finally, one should also keep in mind that the safety of a system shall be maintained in every stage of the whole lifecycle, from the nuclear risk inception until the final decommission.

SMR will bring new designs, new operating models and new technologies. However, most regulators do consider today that the standard basis for nuclear safety, nuclear security and IAEA safeguarding will remain applicable to SMRs. Some adjustments might be necessary in procedures, however they will be limited to the margins, but SMRs will globally have to comply with the existing standards. Particularly, the safety requirements will not be lowered.

1.5.2. *Considerations specific to SMRs*

The specific features of SMRs will have an influence on safety considerations. Some features might increase nuclear safety, but others might raise new difficulties.

As previously expressed, there is a large variety of designs, techniques and even operating models in SMRs projects. It would not be relevant to have an extended analysis of each one, given the fact that most of the projects are not yet stabilized and still evolve. It is however possible to consider several common elements.

<u>Features in favour of an enhanced safety:</u>

- The smaller size and power of SMRs will induce a smaller inventory of radionuclides, thus reducing the potential source term.
- For some SMRs, the use of new specific fuels core designs and technologies might increase core resistance to meltdown risk.
  For instance, the use of new fuels incorporating TRISO could increase the safety. The TRi-structural ISOtropic particle is a small spheric kernel made up of a uranium dioxide, encapsulated by three layers of pyrocarbon and silicon carbide-based materials that prevent the release of radioactive fission products. TRISO particles can withstand extreme temperatures well beyond the threshold of current nuclear fuels.

  Another example is the molten salt fuels under study, a liquid fuel where the fuel is directly mixed with the moderator and the coolant. This could allow new passive safety designs where it would be possible to drain partially or totally the core if needed.

  Another interesting technique is given with the pebble bed reactors, where the fuel is in the form of small spheric balls, which can facilitate onsite fuelling and refuelling as welle as fuel withdrawal.
- The limited power will also reduce decay heat load. In a number of SMRs designs, it could allow the use of passive cooling mechanisms such as natural circulation. The permanent availability of active coolant circuit and heat sink might even not be necessary anymore.

  In the same spirit, several other SMRs rely on a passive safety concept such as gravity given injection, assumed to be more reliable.
- These new techniques (new enhanced fuels and passive safety concept) could result in better resistance and longer grace period (increased safety margins).
- The integrated and compact design (incorporation of all primary circuits in a single vessel) could increase safety in design by reducing the number of SSCs (structures, systems and components), thus reducing the number of possible initiating events and enhancing reliability. For instance, a limited number of external circuits reduces the risk for direct breach.

- In several SMRs designs, the containment requirements could be minimized if over pressurization accidents would not be credible.
- On the contrary to current nuclear installations, most SMRs designs do not need normal discharges.

  The SMRs modules will be built serially in a controlled factory environment. This standardization should increase the level of reliability, and thus the level of safety.

<u>But the challenges are:</u>

a) Regarding the technology, the safety design and the risk assessment

- First, if new techniques could reduce the probability for several accidental events to occur, they will also create new scenarios. For instance, the connection of several SMRs in a modular nuclear unit (such as in the NUSCALE concept) could lead to new interaction risks.
- New fuels with, for several SMR projects, a notably higher enrichment rate (necessary to avoid frequent refuelling operations), will raise new questions regarding the risk of contamination in case of an accident on one side, and the future treatment given to used fuel (nuclear waste) on the other side.
- To be politically, socially, and environmentally acceptable, the safety level to be achieved by SMRs will have to be at least as high as for existing nuclear power plants, may be even higher if SMRs are intended to be deployed closer to urban or large industrialized areas.
- There are numerous SMR project. Some of them are led by experienced companies of the nuclear industry. But others are led either by newcomers to nuclear industry, or even by start-ups with little experience in nuclear safety, nuclear security or IAEA safeguarding.
- Several SMR projects are largely relying on computer modelling for safety demonstration. However, most regulators expect claims to be fully justified and proven by a rigorous test and qualification programme.
- Regarding the reactivity control function, many SMRs projects rely on a theoretical significant negative power coefficient of reactivity. However, all transient effects (like the Xenon peak in PWR shutdown) will have to be considered, in every reactor operating situation.
- Regarding the heat removal safety function, the reliability of cooling systems based on natural circulation will have to be challenged in all accidental situations (including with multiple failure criterion), where thermal hydraulic instabilities might occur.
- Regarding the confinement safety function, most SMR projects do not include a large concrete containment vessel. This means that their containment concept will have to demonstrate an enhanced effectiveness of others primary barriers (fuel cladding, and core vessel & primary circuit). In this respect, the transportation phase might create specific risks to be considered. The need for in-service inspections, reliability testing and maintenance might also be challenging.
- Based on a limited power, most SMR designs rely on the use of passive safety systems. Complex active safety systems are no longer needed. Thus, the SMR design is given to be more simple and thus more reliable. However, the reduction in the number of safety systems tends to be contrary to the in-depth defence concept.
- In numerous SMRs projects, part of the safety relies on the performance of the fuel. This means that the fuel qualification programme (which is not in SMR operator's hands) will be a key factor.
- The transportation of an SMR vessel after an incident or an accident will have to be considered.

b) Regarding the operating and the deployment model vis-à-vis the legal and regulatory framework

- Several projects are considering to remotely operate the SMRs, which will obviously raise new questions regarding local accountability, site management, organization for maintenance, delays for intervention in case of an incident, as well as huge cyber challenges.
- The regulatory approach to suppliers might have to be further developed and harmonized if the SMR is intended to get a license in several different countries.
- In several deploying models, the SMR is manufactured, fuelled or even tested (first divergence) in the factory, and then deployed to the final destination. It only comes back for mid-life refuelling (for instance), or for the final decommissioning. In such a scheme, the question of the transportation of a nuclear unit with a mass of radioactive material in a geometry intended to reach criticality will be a major difficulty. Solutions might be practicable (add neutron absorbing material for transportation; transport the neutron source; for thermal neutron reactors, transport the moderator; or a combination of those options). However, the demonstration that the transportation is and will remain safe in all possible conditions will be challenging. In this respect, models with on-site fuelling seems easier to deploy.
- If fuelling is done in the factory, one will have to consider the commissioning of the factory (as a nuclear installation itself), and the commissioning of each of the deployed SMRs. Besides, if the commissioning process starts in the factory and is finalized on site, it might be more complex to organize, notably if the SMR is intended to get a license in several different countries.

c) Regarding other various elements

- Depending on the expected SMR lifecycle, the length of the license and the interval between periodic safety review will have to be adjusted.
- SMRs will have to face the question of planning emergency zones and maintaining on-site emergency response capacity. This point might limit the number of sites where SMRs could be a relevant option. In this respect, the deployment on an already nuclear site far from urban areas, or the deployment on an industrial conventional site close to urban areas will be very different.
- Safety oversight by regulators, on-site inspections, and inspections of internals and SSCs will need to be addressed, given the very compact design of SMRs. Also, new activities such as manufacturing and transportation should be monitored.
- The implementation of IAEA safeguards agreements regarding non-proliferation might be a sensitive but important point given the type of fuel (higher enrichment rate), but more complex to carry out when considering SMRs in the factory, during transport and on site (possibly in a different country).
- The nuclear security of SMRs will have to be further investigated, notably when considering the risk of a physical aggression during a transport or on site (possibly in a different country).

1.6. Uses and industry consideration

1.6.1. New opportunities of nuclear power uses

In addition to basic electricity production, SMRs provide access to nuclear energy for industrial activities which until now were dependent on an external network, whether it is an electricity grid, a natural gas or oil network. This network gives them the primary source of energy that they transform into electrical power for their machines and equipment, via a dedicated combustion turbine power plant for example, or a factory transformer. Access to a stable, permanent, independent source could revolutionize their access to energy since they will have a dedicated production unit that will last for 10 or 20 years. This revolution is technical, but also contractual. Many sectors of industry and large energy consumers are very interested, if only to produce carbon-free hydrogen, for example.

Overall, behind the term SMR hides a multitude of projects ranging from a few MW(e) (microreactors) to several hundred MW(e). The prospects for use are also very diverse, depending on the sector concerned:

- Electricity production in isolated regions or with weak electricity networks
- Balancing the electricity grid with intermittent renewable energy
- Heat production near cities
- Production of fresh water by desalination
- Electricity production for heavy industry, metal mines requiring large power consumption, production of industrial hydrogen for trains and clean vehicles, product refineries for the creation of molecules and various products themselves isolated from the usual sources of energy.

The SMR chosen according to its destination, will therefore have different flow characteristics, pressures, and operating temperatures, but also a design, adapted to its use. The size of the final unit and the planned industrial production and delivery scheme will respond to specific requests, all on standards well framed by the control bodies.

The nuclear sector is very interested in these devices because this development offers new prospects and new outlets for the nuclear industry.

An important aspect today that should not be overlooked concerns decarbonization. Indeed, SMRs, given the prospects and their apparent ease of installation compared to large units, make it possible to actively participate in decarbonization over a very broad spectrum of the economy, and for all countries according to their industrialization and their energy needs.

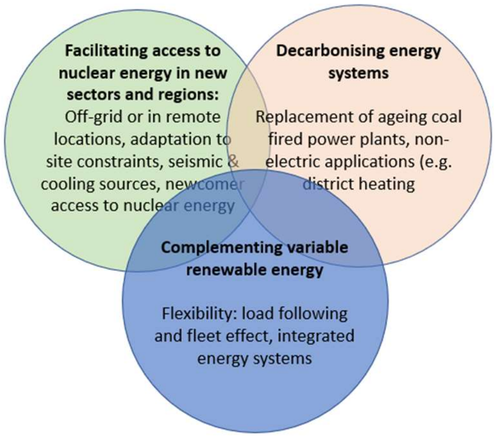
To make the comparison between the different sources of energy and show the interest of the SMRs for industry, we recall below the equivalent CO_2 emission factors for the different energies (including green & renewable energies). Concerning the uses of SMRs, an interesting use case would be the replacement of the aging fleet of coal-fired power plants in the United States; 60 GWe with capacities between 50 and 300 MWe which were built before 1976 and will have to be replaced (see NEA 2016). The launch of so-called renewable energies takes part of this into account, but the need for overall stability will give SMRs the opportunity to be present in this energy mix.

Estimation of CO_2 emissions by type of energy:

- ✓ Kg carbon equivalent: By definition, one kg of CO2 is worth 0.2727 kg of carbon equivalent
- ✓ Ton of oil equivalent Toe, corresponds to the calorific value of an “average” ton of oil

Nuclear	19 kg carbon equivalent per Ton of oil
Wind	32 kg carbon equivalent per Ton of oil
Solar photovoltaic	316 kg carbon equivalent per Ton of oil
Natural Gas	651 kg carbon equivalent per Ton of oil
Oil	830 kg carbon equivalent per Ton of oil
Diesel oil	856 kg carbon equivalent per Ton of oil
Coal	1123 kg carbon equivalent per Ton of oil

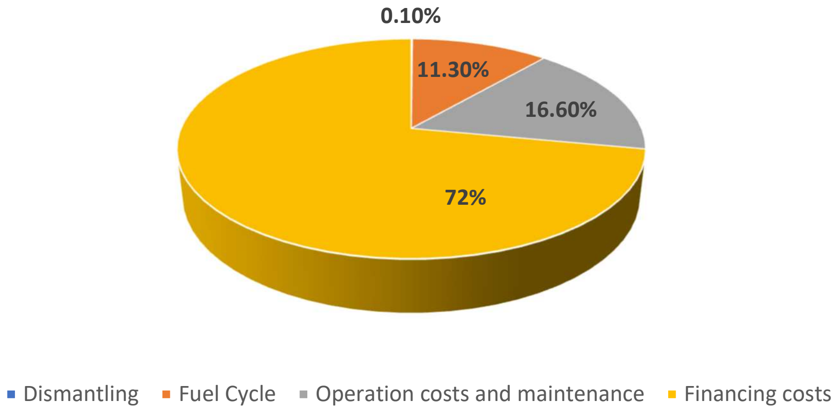
At the view of these figures we understand why the SMR technology is of interest. At the view of the different technologies which are proposed, and the need to replace the fossil plants plus the necessity despite the growing up of green energy, to stabilize the grids, OCDE NEA established a key factors scheme. The crossing of 2 or 3 factors can produce a strong argument to replace existing source by SMR technology.



It should be noted that, for insurance purposes, all these reactors once fixed in the host state remain nuclear installations within the meaning of the Paris or Vienna Convention. Their operators will therefore have to answer for the responsibility incumbent on them according to the heads of damages of the Paris or Vienna Conventions for countries that have ratified them. The consequences are important in terms of insurance.

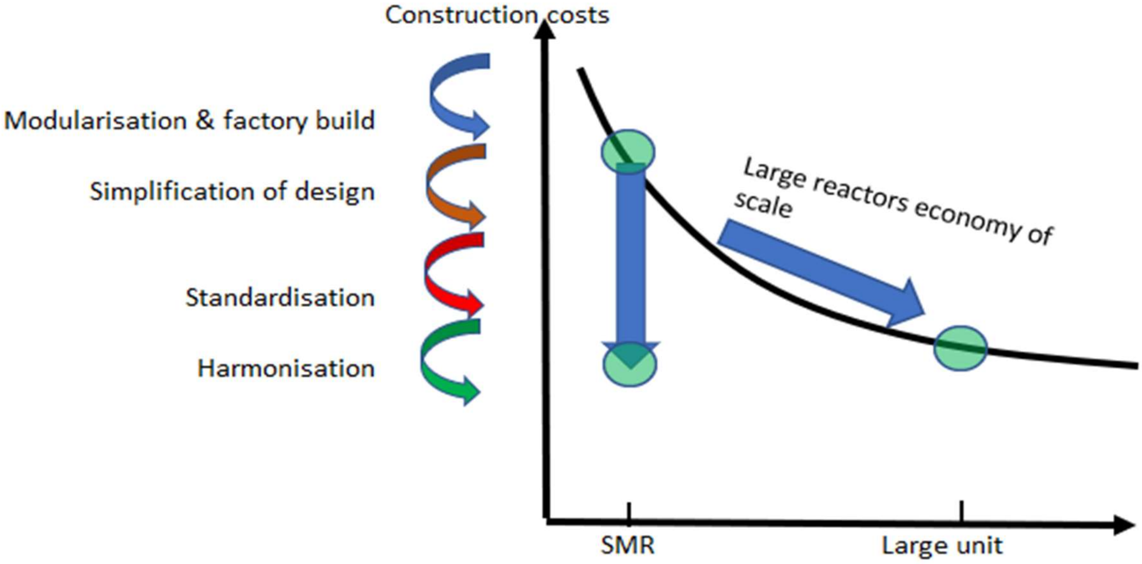
1.6.2. Advantages and inconvenient

The benefits of SMRs are at different levels of the project. Most projects set themselves the objective of simplifying the design, reducing construction and assembly times on site, and modularity allowing adaptation to the environment and the needs of the operator. Electro-generation is a capital-intensive industry, the investments for construction represent a large part of the total cost over time of a power plant, especially if we compare with a power plant running on fossil fuels, gas, or coal. Conversely, operating costs are lower spread over the life of the plant. A reduction in construction project costs should therefore generate a faster return on investment and solve one of the major problems of nuclear power.



Distribution of the production costs of a high-power plant for a load factor of 85% and a lifetime of 60 years

To act on the project costs, the designers rather than moving towards a size effect, worked on the design, the increase in factory work, the repeated modularity on a unit, allowing an effect of large series on some components. This results in substantial savings, in particular with reductions in construction times, which are essentially no more than assembly times at the chosen location, reduced to a minimum for microreactors. In this case, the fuel that may be loaded in the factory for some kinds of SMRs, is then no longer a site issue but a factory manufacturing issue. The reactor in that case being used as a “transport container”. For the Russian barge Akademic Lomonosov, pushed to 100% assembly on the "shipyards", only travel times, mooring, connections and validation tests will remain, as well as the increase of power load (ramp) and divergence time on the final site before operation. In the Russian example it should be noted that first divergence was done on the “shipyard” site before transport. The barge was already when moored at quay, a nuclear facility before traveling. The first divergence location is very important as it will from that moment, categorize the equipment as nuclear installation (according to NMA 1975 (a) frameworks) or simple fuel material in a container.



Variation Construction costs

It should also be considered that the drop in nominal power leads to a reduction in the figures in terms of physics and mechanics. The quantities of heat and energy to be evacuated are smaller. Certain ancillary and complex systems and circuits designed to overcome the drawbacks induced by the size of the power stations and the evacuation of the powers no longer need to exist in their entirety in the case of an SMR, they can be satisfied with a channel of passive evacuation. Examples include natural circulation of water and steam in the boiler (power evacuation), possible removal of boron circuits (control of reactivity) for certain concepts, etc. safety is improved, the consequences of an incident or even an accident are modified with a downward trend, which can also promote acceptance by the public.

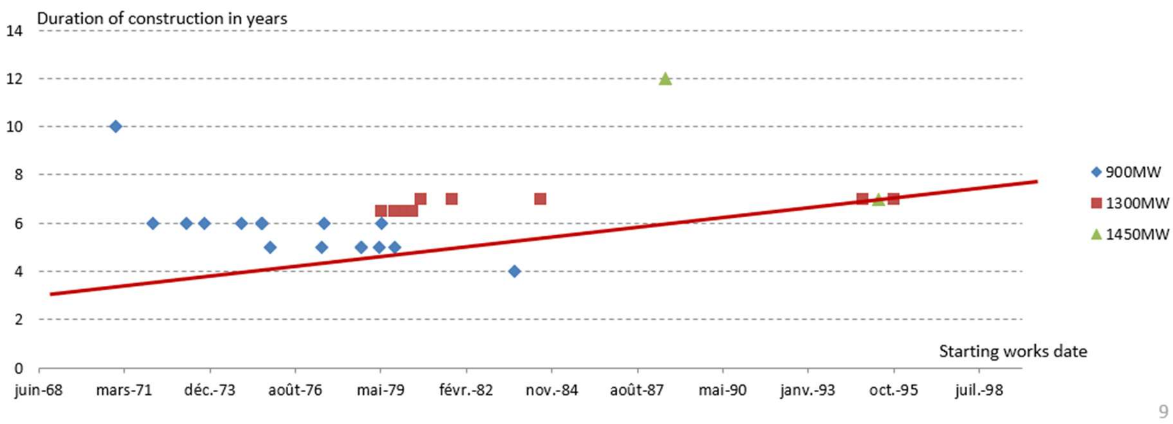
The most important drawback of SMRs is the rapid proliferation of nuclear risks. Indeed, with technologies adapted to industries, the increase in the number of systems and operating with fuel with high enrichment rates, the risk of proliferation as well as its consequence the attempted diversion for military purposes or terrorist goal considerably increases.

1.7. Time schedules

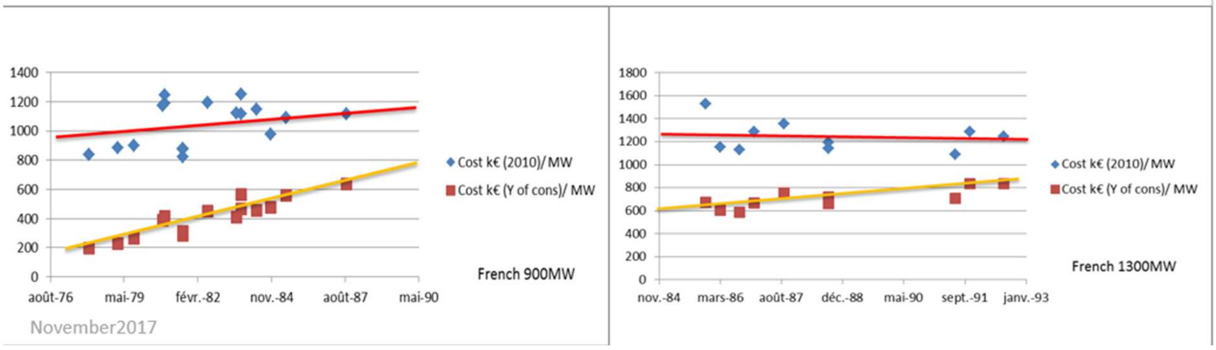
1.7.1. Construction time schedule for big nuclear power plant and an SMR

In view of the history of construction projects for large nuclear power plants, we note that the construction times, regardless of the era and since the 1950s, are counted in years.

Licenses for build and authorizations nowadays go through public inquiries and take a lot of time. The longer a project, the more expensive it is in nuclear, the daily values of company mobilization on the sites are very expensive in this industry, especially during the final phases of construction and start-up, (for example, around 300 mobilized companies are needed on a 1600MWe plant at the end of construction and must be kept on site in the event of delays). As a result, projects, even benefiting from the "Repeat Order" effect after a FOAK ("First Of A Kind"), remain very expensive. We will refer for example to the report of “La Cour des Comptes” on the cost of nuclear power in France in 2012. The average cash advance for the construction of the park was 3.24 years in 2010. With great disparities in construction times, respectively 10 and 7.6 years for Chooz and Civaux for the 1450MW series. Without going into details, we can imagine the cost of the interim interest required in the event of a delay in commissioning with conventional financing (BOT, BOO, etc.).



Average Value French units M€ at date and (value 2010)		At Date per unit	(2010) per unit	variation
Average units	900MW	360	943	262%
Average units	1300MW	916	1614	176%
Average units	1450MW	1571	2090	133%



Done according to Credit French Cour Des Comptes and further EDF figures

The example is even more striking when we look at the durations of construction of the European EPRs, (costs multiplied by 3.3 and times by 3.5) These durations of 10 to 15 years also make them confront unforeseeable and therefore unanticipated economic problems.

For SMRs, the equation of construction and investment costs arises in another way. Development and construction times are much shorter or will be anticipated, using design already well known at nuclear laboratory research level. Different financing methods can be put in place. The costs of the projects are distributed in a more standard way and even if the values remain expensive per MW(e) initially; the progressive start-up of the whole allows a quick payback to avoid the disadvantages of financial costs, credits, interests and debt management. It should be noted here that one of the attractive financing principles can be a system derived from the method used for the financing of aircraft.

Indeed, although it seems difficult, if we compare an SMR to an aerial device, there are many similarities in the development project[6]. Both are manufactured in the factory, highly monitored by the authorities in charge of security (aviation or nuclear), subject to numerous recommendations, design rules, and manufacture, deployed based on equipment fleets, with a strong standardization. Given these points, why not finance them in the same way?

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[6] *see the studies of Vincent Zabielski Pillsbury Winthrop Shaw Pittman in References*

Leasing with a financing company would make it possible to amortize the costs, per unit of SMR, but also by the modularity of future power plants and the possibility of options.

For an SMR, the installation on site should be very fast, 6 to 8 months (24 months with civil engineering for large SMRs) and reduced to 1 month for micro reactors. The result is a very different financial package. The production of electricity may begin (according to Authority decision) as soon as the first complete module is installed, and well before the end of construction of the plant, which can be extended and even be subject to the addition of modules.

We are very close to the standards necessary for construction and gas turbine power plants from micro turbines to large powers…

2. LEGAL ASPECTS

2.1. The conventions' liabilities and geographic scope's applicability to SMRs

The nuclear liability conventions define the liability of the operator as the liability of the "operator of a nuclear installation". In consequence, the first question, one might want to answer when contemplating an SMR design and its deployment scheme, is to know if it meets the definition of a "nuclear installation" under the conventions, and if not, if it falls at all under their cover. With regards to the conventions, deployment schemes related to land based fixed SMRs (see figure) are not different from those of current nuclear power plants provided that the reactor is not factory fuelled. Novelty in this matter rather lies with mobile SMRs and in general with SMRs that are factory fuelled. For this reason, this chapter concentrate on them.

Think for example about the following deployment scheme for a factory fuelled SMR: (1) one or several supplier countries produces and fuels the reactor; (2) the reactor is shipped to the host country where it is installed on-site and/or assembled with the rest of its modules, if any; (3) the SMR is operated in the host country; and (4) transported back to one of the supplier country for defueling and decommissioning at the end of its life (see figure). During step one and two, we have a SMR being produced, loaded with fresh fuel, and transported. As such the SMR will start to fall under the convention as soon as it received its load of fresh fuel. Indeed, from this moment on, it will contain fresh fuel, which either falls –depending on the nature of the fuel– under the convention's definitions for "nuclear fuel", "nuclear material" or "nuclear substance" from which liability, that is the paramount subject of the conventions, will derive. Does the SMR becomes a "nuclear installation" as soon as it leaves the premises of the fuel loading factory? Probably not. Although it already possesses a liable operator –the one of the "nuclear installation" where it gets fuelled[7]– the SMR itself, is, at first, nothing else than radioactive substances under transport (see also remark on the application of the NMA1975 nuclear exclusion clause to SMRs). In this respect, a peculiarity of the convention's applicability to SMRs is that an "operator of a nuclear installation" might receive a license to operate a reactor (or "nuclear reactor" under the VC and RVC), that has, according to the meaning of the same conventions, not yet become a "nuclear installation". But then, when does the SMR become a "nuclear installation"? The definitions provided for "nuclear installation" under the Revised Paris Convention (RPC) and Vienna conventions[8] are quite similar and generally cover all SMRs that are land based and fixed. Once more, complications arise in the case of SMRs that are comprised in a means of transport or in any structure that can be assimilated to a means of transport, for example, mobile factory fuelled SMRs. In this respect, the RPC excludes "reactors other than those comprised in any means of transport"[9]and the Vienna conventions, which are less restrictive, exclude means of sea and air transport while specifying that cases in which the nuclear reactor is used as a source of power, whether for the propulsion of the means of transport or for any other purpose, are not covered

[7] Maybe not the same as the one where it has been fabricated.
[8] Here the designation "Vienna conventions" refers to both [1] and [3], whereas "Vienna Convention" (VC) refers exclusively to [1] and "Revised Vienna Convention" (RVC) refers exclusively to [3].
[9] See [4], Article 1(a)(ii).

by the conventions. Accordingly, it can be directly concluded that all SMRs used for the propulsion of a means of transport or to produce energy for any purpose related to their transport are excluded by both the RPC and the Vienna conventions. Still, for the mobile factory fuelled SMRs discussed here, energy production takes place only after the installation is complete and at no time is energy provided for the propulsion of the means of transport or for any other purpose related to transport[10]. The question of whether SMRs comprised of a means of transport might be covered by the conventions has been more generally addressed by INLEX that concluded that "the exclusion does not apply to transportable nuclear power plants"[11](TNPPs). Additionally, the explanatory text of the VC affirms that TNPPs in a fixed position would be covered by the convention. These might be land- and marine-based. Furthermore, INLEX's conclusion also applies for marine based SMRs, "that are floating reactors, anchored to the seabed or the shore, and attached to the shore by power lines"[12], which correspond to the mobile SMRs discussed here. On the other side, marine-based SMRs installed as floating reactors anchored to the seabed, fixed platforms at sea or as immersed capsules anchored to the seabed might bring new challenges to the conventions. Indeed, they are TNPPs, but they might not be "attached to the shore by power lines"[13], especially in the case of platforms and floating reactors as illustrated in Appendix figure. Their status might require further clarification and probably a relaxation of the INLEX position, especially if exotic SMRs deployment schemes and new usages, other than electricity production, emerge. In this respect one might for example question the status of marine-based SMRs that would be fixed but wouldn't provide energy to the shore through power lines. Today they would most probably fall outside of the convention's framework and will not be discussed further here (see note of Figure). The RPC, for its part, excludes all reactors "comprised in any means of transport", but the arguments presented by INLEX in the framework of the Vienna conventions would probably be applicable. Hence, it can be concluded that mobile and factory fuelled SMRs that are not producing any energy for whatever purposes within the means of transport in which they are comprised, and provided that their transport has stopped, could be covered by the conventions. From the discussion above, it can also be confirmed that these SMRs are not to be considered "nuclear installations" when being transported, but rather as radioactive substances under transport. Furthermore, the conventions contains provision that deal with the case where nuclear material is transported that is "intended to be used in a nuclear reactor with which a means of transport is equipped for use as a source of power, whether for propulsion thereof or for any other purpose [runs until] the person duly authorized to operate such reactor has taken charge of the nuclear material …"[14] or, when the SMR is received back, for example by the refuelling factory, "after [the operator] has taken charge of the nuclear material from a person operating a nuclear reactor with which a means of transport is equipped for use as a source of power, whether for propulsion thereof or for any other purpose."[15] Looking at these provisions with mobile factory fuelled SMRs in mind, on comes to the conclusion, that they, first, do not only apply to the refuelling of SMRs that might not qualify as such under the convention and, second, that they also apply to the delivery of mobile SMRs in general, obviously in this case the "nuclear material" would be already contained during transport in the nuclear reactor it is intended to be used in. How does this help? If the SMR is delivered to an already existing nuclear installation (for example in the case of the delivery of a truck-mounted SMR on the site of an already existing nuclear power plant) in the host country, it does not make a big difference to think of it as the delivery of nuclear material intended to be used in a nuclear reactor as written above, but because there won't probably always be a receiving "nuclear installation" or "operator of a nuclear installation" present in the

[10] A very good example of such an SMR is the Akademik Lomonosov, which was towed from its shipyard to its installation site where it remains fixed and produces electricity for land-based uses only.

[11] IAEA, The 1997 Vienna Convention on Civil Liability for Nuclear Damage and the 1997 Convention on Supplementary Compensation for Nuclear Damage — Explanatory Texts, IAEA International Law Series No. 3 (Rev. 2), footnote 85.

[12] IAEA (2019), "Nuclear and Radiation Safety, Report by the Director General", IAEA Doc. GOV/2019/27-GC (63)/4, p. 28.

[13] *Ibid.*

[14] See [1], [3] Article II(1)(b)(iii) and (iv).

[15] *Ibid.*

host country before the delivery of the SMR is completed, cases will emerge where these provisions might become useful. Similarly, on the way back to the supplier country, the question arises whether a “nuclear installation” or “operator of a nuclear installation” is always present after its departure. For example, the perimeter where a floating SMR is anchored onshore only becomes a nuclear installation when the SMR arrives. Will it stay a nuclear installation when it leaves? Will there then be an operator of a nuclear installation in the host country? This is particularly relevant when receiving back an SMR in the supplier country since in the absence of an operator in the host country, the liability would have to be born from the start of the transport by the operator of the refuelling factory after being transferred from the person “operating a nuclear reactor”. One begins to see the challenges that might arise from the definition of an operator under the conventions. Indeed, similar questions arise in the case where SMRs would not be comprised in the means of transport but would still be factory fuelled. Another complication arises when countries involved are not contracting countries to the same conventions. In this case, the liability of the operator in the supplier country would continue to run indefinitely if there is no unloading (upon arriving the host-state) of the nuclear material from the “means of transport by which it has arrived in the territory of that non-Contracting country” [16]. On the way back to the supplier state, the liability of the operator of the refuelling factory would start only after [the nuclear material] has been loaded on the means of transport by which it is to be carried from the territory of that country”[17]. Both loading and unloading would suppose the presence of a self-motorised means of transport, in which the SMR is lodged during transport, which could be technologically challenging. If SMRs are destined to remain in the means of transport in which they are transported, a clarification of the convention’s intent would be required. This shows us the additional challenges that might arise if collaborating countries are not parties to the same conventions.

But that is not the end. The whole story gets even more complicated when contemplating the geographical scope of the conventions, that, in addition to the fact that the current international liability framework resembles a patchwork, makes international SMRs deployment quite challenging, especially regarding factory fuelled SMRs that are going to be shipped around the globe. Indeed, with the transfer of liability from one operator to another who might be party to different conventions, the possibility arises of damages being inadequately covered and reciprocally managed by the country involved. Although such issues are already present today in the framework of transboundary damages, they might get more complex with the deployment of marine-based SMRs and if these are to be deployed outside of the territory of conventions’ parties. This is not only a problem for victims in the case of an accident but could also have a significant impact on the effective deployment of SMRs. For example, the legal channelling of all claims to the operator offers all implicated subcontractors/suppliers the juridical certainty that they will not be confronted with claims brought against them by victims in different countries and jurisdictions, which makes their participation in such projects possible (see Figure). If victims of uncovered damage in the host country can bring claims against the supplier of an SMR in the supplier country, the latter might reconsider becoming involved in the first place. Let's illustrate with a few examples in the case of the RPC. Damage suffered on the high seas by a French ship due to nuclear substances emanating from a British SMR operating in British territorial waters off the coast of Scotland would be explicitly covered under the convention (both countries are RPC states) whereby a marine-based SMR in use in the territorial waters of a contracting party to the RPC causing damage to/on a ship or aircraft present on the territory of an “excluded” non-contracting state, independent of the state they are registered in (even in a RPC state) would explicitly be not covered under the RPC. In the framework of the VC, the case of the Akademik Lomonosov might be of interest. Indeed, one might conjecture whether damage caused by such an SMR and suffered on the territory of a non-contracting state to the VC would be covered under the VC. Such a situation might occur in the Baltic Sea between VC and RPC

[16] See [1], [3] Article II(1)(b)(iv).
[17] See [1], [3] Article II(1)(c)(iii) and (iv).

states if the two are non-contracting parties to the Joint Protocol[18]. Nonetheless the VC defines that, in such cases where the exact position of the accident involving a mobile SMR cannot be defined or occurred in the territory of a non-contracting state or in no state's territory, jurisdiction of the case would generally belong to the installation state.[19] This implies that the VC can be interpreted as "allowing the applicable national law to also cover damage suffered in non-contracting States"[20], in this case, Russian national law. The question of the limits of the territorial scope within which damage can be suffered has been clarified in the RVC.[21] In particular, the RVC applies to nuclear damage wherever it is suffered[22] while giving the possibility for a state party to allow exception similar as the one already present in the RPC.

2.2. Applicability to SMRs of reduced amount of liability under the conventions

The conventions foresee minimal requirements in terms of the sum for which operators should be liable in the case of an incident and the obligation for operators to maintain insurance or financial securities to ensure that they will be able to meet the amount of their prescribed liability (see remark in Appendix). Under the RPC and Vienna conventions, provisions are present that give states the possibility of reducing the liability amounts within certain limits.[23] The idea of these provisions is to maintain a graded approach to risk with "the aim … to avoid burdening the nuclear operators concerned with unjustified insurance or financial security costs". [24] In such case, an obligation is imposed on the state to make public funds available for compensation for nuclear damage arising from a nuclear incident that would exceed the reduced liability amounts up to the prescribed minimal (non-reduced) liability amounts.[25] The reduced liability amount provided by the conventions for low-risk activities and installation is 5 million International Monetary Fund special drawing rights (SDR) in the case of the RVC and the Annex of the Convention on Supplementary Compensation (CSC), and 70 million euros for the RPC, which also provides a limit for transport of 80 million euros.

Regarding SMRs, it will be up to the states to decide where they want to place the bar between the reduced liability amount and the minimal liability amount. This exercise contains several difficulties:

Multi-module/multi-unit/multi-operator aspects of certain SMR concepts:

- Specific bands of power for individual modules might be defined, within which liability amounts are relaxed up to a certain aggregate power, per operator, per site.
- SMRs are not only expected to produce electricity. Defined bands might also be expressed in terms of the thermal output of a reactor.
- The environmental boundary conditions for different SMRs might be extremely diverse.

The direct environment of the nuclear installation in terms of population[26] as well as the extent of its EPZ might be considered while defining the liability amount.

Regulators will have to consider these parameters when defining the minimal liability amount for different types of SMRs so as not to favour one type or one design over another or certain power/number combinations of modules that would lead to inconsistent liability obligations between designs or situations that are otherwise equivalent from a safety point of view. The establishment of technology-neutral performance or risk-informed guidance for states under the RPC and the Vienna conventions would be very useful and help harmonise how states set the

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[18] The JP forms a bridge between the RPC and the Vienna Conventions. Among other things, it specifies which of the RPC or the Vienna Conventions applies, and which state jurisdiction applies, in the case of transboundary damages between states that are not party to the same convention but party to the JP.
[19] See [1], Article XI.
[20] See [2], p. 30.
[21] See [3], Article I A.
[22] See [3], Article I A(1).
[23] See [4], Article 7(b), [3], Article V(2) and [7], Article 4(2).
[24] See [5], para. 68.
[25] See [4], Article 10(c) and [3], Article 5(2).
[26] For example, where SMRs are used for district heating.

bar when establishing reduced liability amounts. Considering the important differences in the levels of the liability amounts between conventions, for example, between the RPC and the Vienna conventions, one can readily understand that such recommendations only make sense in the framework of a specific convention or for states who are party to conventions offering similar minimal and reduced amounts of liability.

The SMR's environment is also likely to produce new challenges in terms of insurance. Aside from the fact that industrial heat or electricity production in combination with industrial installation will revolutionise the vision we have of today's nuclear operators (every industrialist seeking to replace their conventional energy source with SMRs may potentially be operators of a nuclear installation), the possible presence of high-value assets in the vicinity of SMRs with reduced liability limits could lead to either inadequate third-party liability cover or prohibitive increases in premiums. Such questions might necessitate reliable in-depth studies as part of the evidence for the economic feasibility of such concepts.

Also, as most of these risks will have to be covered in the international pooling and mutuals system in the future, it is up to that system to find alternative solutions to ensure that capacity allocation towards such risks stay attractive, solutions on which section 3 of this publication offers a reflection.

Finally, one might want to point out that, especially for mobile factory loaded SMRs, damage to the means of transport under the conventions may become a subject of interest. Indeed, if fuelled SMRs are to be transported around the world and, *a fortiori*, if new technologies and dedicated vessels are to be developed, owners of such vessels will require certainty concerning indemnification in the case of accidents. There is no implicit mention of the minimal liability amount towards damage to the means of transport in the conventions. For example, the VC states that operators should not be liable for such costs and gives states the possibility of legislating on the matter provided that the operator's minimal liability amount for nuclear damage remains untouched.[27] The RPC also includes this possibility provided that the "liability of the operator in respect of other nuclear damage"[28]is not reduced below 80 million euros (the minimum liability amount for transport). In this regard, the RVC is more generous because it provides for a possible reduction of the minimum liability amount for damages other than transport of up to 150 million SDR, which would represent half of the highest minimum amount for which the operator can be held liable.[29] Care will be taken by transporters to check that the liability amounts offered in the different countries traversed, as well as the amounts contractually agreed with their clients, are adequate. If technologies required for fuelled SMR transport become much more costly than the actual technologies, some steps may need to be taken to reflect this new situation in the convention.

3. UNDERWRITING CONSIDERATIONS

Globally a lot of factors will have an influence on the insurance, among them we note, the structure of the operator (who is the owner of the unit?)[30], the manufacturing and pre-erection scheme, (100% in factory or only modules with final assembling later?), the design (with first criticality in factory for micro reactors or on final site?), then transportation needs, the location of the fuel loading the type of fuel, the operation mode (fully automatic or with human control?), the anticipated maintenance, then the environment (industrial area or isolated, urban environment or in remote area, offshore etc… ?).

27 See [1], Article IV (5) and (6).
28 See [4], Article 7(c).
29 See [3], Article 5(1)(a).
30 Owner and operator are two different juridical concepts. In the case of SMR they might even be not the same person. Under the convention, the responsibility for nuclear damage is attached to the operator

As a general view, and without considering pure conventional equipment and buildings which are outside the nuclear risk exposed zone, a conventional construction cover is possible until radioactive material is involved.

This means for SMRs that a conventional cover is commonly possible only in an on-site fuelling model, and for the manufacturing and the transportation of non-nuclear elements. On an operating site and for fuel transportation, a nuclear cover is necessary.

For a factory fuelling model, the only option is a nuclear cover for both sides (as far as the reactor arrive on final site, & expected for some specific conventional buildings), the manufacturing (as factory get fuel in stockpile), the transportation and the operation. The way to drop from a construction conventional cover during the assembly (if we withdraw the problem of sites with multi-units on construction), is driven by the NMA 1975 a, from all treaties and single policies. In view of these parameters, we will now study the insurance consequences on pure property cover.

3.1. Covers analysis

Depending on the use of the energy generated by the reactor, a certain number of consequences will be induced on the risk that reinsurers and insurers will have to cover. Electro-generation is one of them, but we must also mention district heating, the raw steam delivered for the industrial process, whether to produce fresh water, or to run an ore preparation plant. Each use will have its own specific. Overall, the risks generated on the nuclear island could be classified under different headings. They will be linked to the interactions between the two systems and to the parameters required at the reactor outlet. One should not overlook, for micro reactors, the fact that the fuel can be loaded in the factory. As such the reactor will be present on the destination site before the end of construction, this then results in a modification of the EAR/CAR which will have to cover nuclear risks (or let it jump into an operational cover), and at the same time assume overexposures on construction risks for the loaded reactor, (welding, lifting, site partially built and assembly partially completed, presence of construction machinery, handling, etc...).

3.1.1. Conventional and nuclear boundaries limits

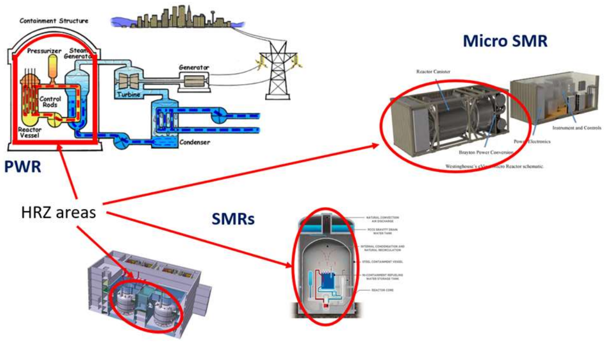
As indicated previously, all contracts for damages and all risk assembly tests, including in the insured equipment an element giving rise to a nuclear risk, are provided with the clause **NMA 1975 (a),** which we will find in the appendix. It is also present in reinsurance treaties. This clause excludes the nuclear risks linked to the reactor, and defines geographically on the NPP ground, the zone concerned by the exclusion.

But is the clause applicable to SMRs?

a) For devices that are assembled at the destination site, there are no changes insofar as the conventional EAR/CAR continues throughout the assembly of the modules coming from the manufacturers' factories, and there is partial transfer of the nuclear risk when the fuel is loaded in the reactor vessel, as for a large power plant or a fuel production plant when the latter is put into operation. After fuel loading or criticality, conventional construction insurance is altered by NMA12975 exclusion, which takes out specific areas ie the High Radioactivity Zone (HRZ[31]) as well as specific perils. The clause operates in the same way as for a large power unit. The fuel arrives on site and is loaded in the vessel, the unit goes into nuclear operation risk and the conventional risks is decreased accordingly. It is worth looking in detail at the positioning and definition of the HRZ, which usually includes the reactor, but also the spent fuel storage pools and the transfer buildings. Indeed, for an SMR for which the compactness reduces the size of the plant, or the storage pools are not necessary, the HRZ should logically be defined

[31] *HRZ: Hight Radioactivity Zone as per NMA 1975 a*

as the whole prefabricated reactor module, its main boundaries being connections to secondary water inlet and steam outlet.



Comparison of HRZ for large NPP, SMR & micro SMR

b) For reactors whose size allows them to be factory fueled, the fuel is transferred to the reactor in the manufacturer's workshops. The reactor acts as a transport cask and therefore the arrival of the fuel on site takes place on the arrival of the first reactor module, which can be considered as the HRZ, and the activation of the nuclear risk policies takes place at this moment. The subject is even more marked if the fuel is tested in the factory and therefore activated before it leaves (first criticality). A specific operation or device should allow to maintain the fuel under safe condition during transportation and on site, and maintained in place until commissioning ends

In both cases, we will have to wonder about the impact on the implementation of nuclear insurance in the case of a multi-unit plant on the same site, (it can be solved by a partial take over with identified time schedule). Indeed, the commissioning of the first unit or the first reactor (for systems with two or more nuclear boilers), determines the date of implementation of the nuclear risk cover, then cover of mutual contamination to be anticipated with specific clauses and dedicated sublimits, the NMA 1975 a will drive the perils. The conventional cover will continue to operate for other parts, units and conventional buildings and extensions.

Concerning the extensions, underwriter shall pay attention to the definitions but also to extensions such as “Inland transit, for which definition of the transported good is of importance to cover or not.

Note: *it will be necessary to be vigilant on transport insurance, and comfort clauses related to hidden damage and not to redeem nuclear risks. Another technical question will be to design the canister to transport a damaged micro SMR which is internally contaminated. How to maintain the cold source in operation, size of the unit? Duration of transportation?*

3.1.2. Design risk

The design risk must be the subject of particular attention, in fact it will be necessary to carefully analyze the definition of the coverage, the origin of the design covered (or not covered), as well as the definition of the insured persons under the contract. As the object of the guarantee is carried out in the factory, and as the final installation site is only the scene of the construction of the foundation, stability elements and assembly/connections of the SMR modules, the geographical definition of the covered site must also be the subject of all attention, (for the conventional risk and for the nuclear risk). We will pay attention to the type of cover without or with the defective part. The time and costs to get access and for repair can be extremely high. The exposure will then be reinforced by the DSU or ALOP presence as extension of the cover. The administration time & costs and the consequences, which usually for conventional risks can be assumed, in this case can have a big impact on the total incident costs. In fact, in contrast to big plants for which the return to factory typically only concerns pieces of equipment, for an SMR, there is a great risk that it will not be possible to repair on final construction site and that the whole SMR at once might have to be returned to factory , in which case the impact for the insurer is completely different.

Mindful that based on the re-definition of the HRZ suggested above, the most impactful events, obviously linked with the innovative design of the reactor section, would presumably be borne by nuclear insurance to a great extent, except for the handling and erection risk before first criticality.

3.1.3 Serial Risks

Whatever the SMR, it will most probably originate from a series production. It will be necessary to integrate risks which until now in the nuclear industry were not localized or perceived in the same way. We will note the serial risk at the level of the general design of the device, for example, and the development of repetitive processes which until now were mainly found only in specific equipment such as the steam generators, or the rods or even the series-mounted fuel processing machines. The study of this exposure must be carried out. This is one of the big changes for this industry. Should we consider serial risk clauses if necessary to balance the transfer? Answer is yes, especially for the micro reactors which will be subject to large production to insure return to the manufacturer.

3.1.4 Natural event risks and locations nearby population

Up until now, the policy for setting up a nuclear risk which is the subject of particular attention, whether it is an industrial site for the fuel cycle or for electro-generation, has always been found in areas with low exposure to natural events, with certain exceptions such as Japan or Taiwan, where all of the territories are exposed to the perils of nature, For SMRs, the picture is quite different since ,by definition, their uses require them to be close to the population or industrial work areas. This results in an increased risk to the population and neighboring property. Similarly, while for large power plants, the location was chosen at the lowest in terms of natural events, for SMRs, it will be necessary to rethink the acceptance of exposure to natural disasters since their number will lead to establishments in comparatively more exposed areas. Subscribers beyond the notions of acceptability by the public, will have to take these parameters into account in their analysis.

3.1.5 Cyber risk

The risk linked to the robotization (cyber exposure) should be scrutinized with care, although the latter is potentially reduced for this type of installation, since indeed at this stage, it is expected that some of the SMRs should operate with a minimum of exchanges with the outside world. However, in some cases, one of the solutions envisaged, particularly in totally isolated areas, is to have a fully automated device, in this case it appears that the equipment, unlike high-capacity plants, can no longer have "air gaps" protection allowing total isolation from the stresses relayed by digital means. The remote operator will therefore have to be subject to the greatest checks and verifications. A new procedure may be put in place including the specifics of remote operation. For the subscriber, an adaptation of the cover will have to be carried out, an exclusion defined according to the exposure to cyber risk.

On the other hand, it will be necessary to be vigilant about the cyber risks induced by series constructions in the factory which are not currently studied on the model of "microreactors" products but in the context of large monolithic installations.

3.2. MPL and scenarios - accumulation driving

The nuclear safety and security of an SMR will be guaranteed through the licensing process of the operator.

It is not a question for the insurer. From their perspective, if the SMR is licensed in compliance with the recognized international standards and with the necessary rigor, it should be considered

as safe from a nuclear perspective (the probability of an accident and the extent of its consequences are acceptable to the public authority).
However, for an insurer whose concern is primarily the cost of an accident when considering a MD or a TPL contract, other elements will have to be considered.
Regarding the Material Damage cover, the perimeter of property to be compensated is critical. The cost might be very different if only the SMR unit is to be compensated, if both the SMR unit and the industrial unit benefitting from the energy produced are to be compensated. It will also be very different if business interruption is guaranteed or not.

Concerning large construction sites and Third-Party Liability cover (for construction perils and for the operator), it is essential to consider the environment in which the SMR will be deployed. Indeed, the 3 following elements are critical when considering the cost of a nuclear claim:

- The human density (Number of residents per km2);
- The capital density (MUSD of capital per km2);
- The economical intensity (MUSD of GDP per km2).

From this perspective, the risk attached to two SMRs of the same type, one by an operator on one of the sites where they already operate a nuclear installation and which is far from urban areas, and another one on an external conventional site with high value industrial equipment located close to a densely populated city, will be very different. It is not something new. Risk already varies from one NPP to another of the same type/power. However, when considering SMRs, this variation will increase depending on the environment where the SMR will be deployed, which should therefore be scrutinized more carefully by nuclear insurers to adapt the cover and the pricing.

3.2.1. Power plant risks

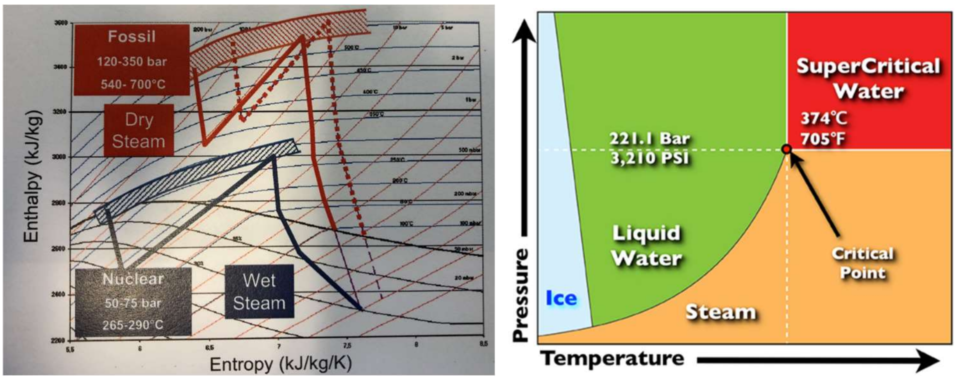
If we look at the studies carried out on the subject, in particular the studies carried out by the IMIA, WGP 24 (02) Machinery breakdown in nuclear power plants, WGP 42 (0) Maintenance and Overhaul of steam turbines, on the conventional part, depending on the different stages of construction, then the operation of nuclear power plants, the main axes of events generating incidents and damage to property, are linked to the steam turbine and generator sets, and to the power transformers, which constitute in insurance the bottlenecks of exposure for machinery breakdown and fire.

It is therefore appropriate, depending on the SMR, PWR, HWR, SCWR or other, to carefully study upstream the parameters of the primary but also the secondary circuit, of the steam cycles, and then to classify the installation according to the risks incurred on the "cold" part, fire, machinery breakdown, take into account the influence of the choices made, the importance of the stress vector for materials and equipment, the type of operation among others.

If we take an example, a large nuclear power station does not produce the same steam parameters as those used for power stations operating on coal. This difference is mainly due to the search for the best efficiency for fossil fuel power plants, in order to increase the quantity of energy produced per ton of coal and to reduce emissions per ton consumed. On the other hand, for nuclear energy, it is operational safety that is put forward to the detriment of efficiency and the steam turbine parameters due to the primary steam parameter do not allow to increase the efficiency.

Examples of steam settings for comparison:

Type	Steam temperature at ST	Steam pressure in bars
Coal supercritical 1000 MWe	565 °C to 585°C	221b
Coal ultra-supercritical 1000 MWe	600°C/620°C°C	275b
Nuclear 1000 MWe	270°C	70b



Credit ALSTOM Documents Steam turbines in nuclear power plants 2010 - Wikipedia

In view of this table and the image showing the energy conveyed, it is clear that the materials will be more "stressed" for a coal supercritical boiler, and that their mechanical properties at high temperature and under high pressure will be sought. It should then be noted that the so-called transient phases of load increase with variations of important parameters will also contribute by their number and by the speed of variation to generate stresses which can lead to faster "wear" when the materials are very stressed. mechanically.

For the nuclear part, following the schedule described previously, according to the type of reactor, (even for other purposes than only power plants), we will carefully study the parameters of the boiler room, heat transfer fluid used and its parameters, which will influence the design of the systems. The control of possible leaks, control of the integrity of the enclosures, the type of use in production and the influence of transitory zones as well as all of the safety systems should be scrutinized with care to have a setting of the guarantees in balancing with the proposed risk to cover.

3.2.2. Risks related to SMRs used in Industrial processes

In the same way as for electro-generation, the risks on industrial processes will be linked to the type of industry supplied with nuclear energy from SMRs, whether mechanical (process steam), chemical or electrical heating. The layout of the reactor may possibly provide additional exposure. The use of steam in seawater desalination, in petrochemicals, or in heating products, leads to very different but well-known risks. The reactor will induce the nuclear risk on the industry concerned and the industry will induce the risks which are specific to it, fire for oil, machinery breakdown and corrosion among others.

It is very clear that the cracking of hydrocarbon molecules for the formation of hydrogen will not have the same consequences on the risk incurred by the plant using an SMR to obtain steam with the correct parameters as for a plant using a natural gas or fuel oil boiler. In the case of a boiler operating on fossil fuels, the industry is already considered as an intensity risk with possible explosion, in the case of the use of an SMR, the risk of explosion remains present, but in in addition we add the possible consequences of the nuclear accident according to the possible scenarios with the type of reactor concerned.

Attached in appendix is the matrix which summarize the exposures.

3.2.3. Nuclear scenario

The size effect, namely that as in physic-chemical reactions, the smaller the reactor, the easier it is to evacuate the residual heat. In the extreme, the presence of a certain amount of cold source and natural convection is enough to stop and keep the whole thing safe. The use of active systems introducing pumps, additional circuits, dedicated materials, etc., which significantly complicates the unit, can potentially be reduced. Scenario related to the loss of ancillary circuits, of the power supply, whether internal or external via a High Voltage electric power line, are minimized or even disappear. It is however necessary to remain cautious in the technical analysis because the evacuation of the residual heat is not the only criterion to be taken into account. If several initial causes can lead to a meltdown of the core are no longer valid, the fact remains that the SMRs remain nuclear units, and cannot be handled like simple steam generators. Indeed, the active nuclear material is present with its reactivity. It must be kept permanently confined, and its reactivity controlled. Basically, it has not been demonstrated that the probability of an accident is lower on an SMR. Passive safety makes it possible to make systems simpler, therefore smaller and less expensive. But in terms of intrinsic accident probability, it is not certain that a low-power SMR with 1 safety circuit, for example, ultimately has a lower accident probability than a larger power reactor but with 4 redundant security systems. Each device will have to undergo the necessary studies and prove to the competent authorities that it meets the safety standards set. This is the whole purpose of obtaining manufacturing licenses.

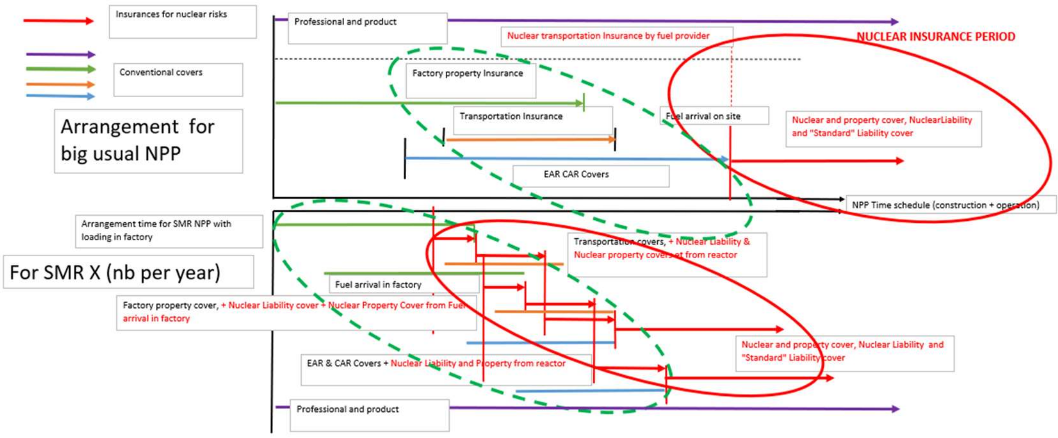
Regarding the scenarios found in the statistical studies of boiler room incidents in large power plants, the handling of heavy elements in maintenance, fuel and the introduction of foreign bodies constitute an important part of the incidents noted. For SMRs, the reduction in core reloading frequencies, the performance of maintenance in the factory, considerably reduce the risks associated with these operations.

Moreover, the degree of enrichment of the material if it reduces the number of re-loadings also leads to residual products that are more complex to process, and therefore to question the economic profitability but also the risks involved, (impact on reactivity control, transportation canisters design, total source term, and dismantling).

3.3. Type of contracts

It should be remembered that in the context of large power plant construction, the border between conventional insurance and nuclear risk insurance is established by the date of arrival of the fuel on the site and its introduction into the reactor. Standard clauses recognized on the markets exist. It is therefore conceivable that for SMRs, if the fuel is loaded in the reactor in the factory, we will have consequences in the timing of conventional and nuclear policies. Two cases will arise, that of small SMRs loaded at the factory, and that of SMRs loaded on the host site. While in the second case, we can intuitively anticipate a compression of time resulting in overall few changes in the nature and positioning of the policies but with a reduction in durations resulting in a real challenge for insurers for their implementation. On the other hand, in the case of a microreactor, the fuel being loaded in the factory, it will arrive at the same time as the reactor to be assembled on the destination site, with moreover all the nuclear covers in place and operational before the end of the assembly and site.

What are the policies that will be put in place for example for an SMR of around 100 MW(e) or smaller capacity, and when should they be active? The diagram below shows the coverages according to the time and the main tasks of the project. It establishes a comparison between a standard nuclear power plant of the “conventional” type, and a small-sized SMR with a reactor loading in the factory (lower than 3.5 to 4.00 MW(e)).



As we indicated beforehand, the implementation of nuclear risk insurance intervenes much earlier in the realization of an SMR project. In addition, the time available for their installation after the start of the project is very short if we consider the date of arrival of the fuel, if necessary, at the construction plant. Consequently, all the parameters needed for the study, and the establishment of prices and conditions must be known well in advance of the project in order to reduce the response time of insurers, as some cover, such as nuclear liability will be mandatory to start operation of the nuclear plant.

In the realization of a classic project for a high-power unit, for reasons of high values and the mobilization of large insurance capacities, the coverage of the construction of the project is complex and slow to set up. Placement is always difficult, and often results in multiple and independent coverage due to the specificities requested by the various stakeholders. We then find on the same project many insurance contracts whose monitoring becomes an additional difficulty for the project given the changes occurring during the realization. These include, among other things, increases in project costs, requests for additional capacity in repercussions, extensions of delivery and assembly times on site given the imponderables of construction. All leading to global coverage extensions

In the case of SMRs, the whole is condensed upstream, the values to be taken into consideration are lower, the durations shorter, it becomes essential to have recourse to a more global, simpler contractual system, with partners and insurance and reinsurance companies, experienced in adapting to the desired coverage of nuclear risks. Several opportunities may open up, insurance systems resulting from the same design as for standard power plants (individual project policies), which will then give more flexibility in establishing the conditions, or anticipated systems, based on production programs, including all the essential covers and which will allow a rapid implementation of the whole, it is the multi-line protocol.

It should however be noted that this last product can create a delicate position during international projects which require the implementation of compulsory local nuclear coverages to comply with the legislation in force. The system will then require good anticipation and a solid knowledge of local insurance demands.

The problem is the same as for the construction of "traditional" type nuclear power plants, but for an SMR the time will run out, and it would be regrettable if a project suffered delays due to poor anticipation of the deadlines for setting up compulsory insurance and for problems of compliance with legislation. To reduce the difficulties in this area, the presence of strong nuclear risks national pools, nuclear mutuals or even captives, with knowledge of the local insurance fabric, and pursuing close contacts between themselves, and with local organizations, as well as with an efficient network of companies then becomes essential.

Summary table: (1) based on specific project policy for NPP and or *in blue a SMR loading of fuel in the factory, (alternative for micro reactor or small SMR 50MWe).*

Different phases of FF SMR lifetime (Fuel Loaded in factories)	**Constructor Country**	**Final Host Country**
Construction (until hot trials)	Conv EAR/CAR *NT TPL (or NOperator's TPL)* *Nuc MD (when fuel loaded)*	(*Depend on legal*) Conv EAR/CAR *From loaded reactor arrival Nuc EAR/CAR or Nuc MD & NT TPL (or NOperator's TPL)* *(when fuel loaded)*
Transportation (specific study needed) (Sender is responsible unless otherwise specified)	NT TPL & NT MD (from fuel manufacturer) *NT TPL (or NOperator's TPL)* *Nuc MD (when fuel loaded)*	*At inlet in the territory,* NT TPL & NT MD (from fuel manufacturer) *NT TPL (or NOperator's TPL)* *Nuc MD (when fuel loaded)*
From Hot trials and operation	No more cover	(*Depend on legal*) Conv EAR/CAR

(when nuclear fuel on the constructor factory site)		*From loaded reactor arrival Nuc EAR/CAR or Nuc MD & NT TPL (or NOperator's TPL)* & NOperator's TPL
Operation	No more cover	NO's TPL *(same)* Nuc MD *(same)*
Major maintenance (depending on the maintenance site)	No more cover *NO's TPL* *Nuc MD*	NO's TPL *(same)* Nuc MD *(same)*
Decommissioning (depending on the decommissioning site)	No more cover *NO's TPL* *Nuc MD*	NO's TPL *(same)* Nuc MD *(same)*
Dismantling (depending on the dismantling site)	No more cover *NO's TPL* *Nuc EAR/CAR or MD*	NO's TPL *(same)* Nuc EAR/CAR or MD *(same)*
Waste depository (normally host state)	NO's TPL	NO's TPL *(same)*

Maritime Insurance: Tug or supply ship (owner or shipper, depending on the charter)

EAR/CAR: Erection All Risks / Construction All Risks
NO's TPL: Nuclear Operator 's Third Party Liability
NT TPL: Nuclear Transport Third Party Liability
MD: Material Damage

The cover will then be even more solid and robust if the main partner chosen can demonstrate its financial solidity and the reserves at its disposal to support the structures in place effectively and quickly, and contribute to the height of its commitment, to settle a claim in accordance with the provisions of the agreement in force in the state hosting the plant. We will also understand here, given the amounts claimed, the importance of having available and sufficient reserves to intervene and contribute effectively to supporting the country affected by the incident.

3.3.1. Project contracts OCIPs and CCIP

Regarding the operating model and the licensing process, several options are possible:

- ✓ OPERATION "FOR ITS OWN": the SMR is sold and operated by a local operator, licensed locally;
- ✓ OPERATION "ON BEHALF": the SMR is deployed and operated by the designer/manufacturer, with its own teams (the SMR is not sold, only the energy provided is sold, as a service). The operator is the designer/manufacturer and has to licensee both in the home country (to build, transport and decommission the unit) and in the host country (to operate it).

In addition, a large variety of options also exists between those two.
Whatever the final model will be, the deployment of SMRs designed and manufactured in a home country but deployed in another host country will raise transnational licensing challenges.

Owner Construction Insurance Policy (OCIP) or Constructor Construction Insurance Policy (CCIP) can be different type of adapted covers, but they are considered as "one shot", very often placed on international markets (especially for very large projects because they require big capacities). OCIP are more convenient for the nuclear risks especially due to the nuclear liability which should be subscribed by the operator, which more often are the owners. For factory fuelled microreactors, as the constructor should become an operator, CCIP can be fit for project.

a) Positive aspects for SMR risks

For nuclear risk, they are adapted to pool systems for liability and MD contracts, the Annual Review is possible; the evolution, the adaptation according to the markets easier for the customer and the insurer, the modifications of shares according to the capacities of the pools are achievable, but they must be followed and renewed every year.

b) Negative aspects for SMR risks

For construction contracts, these are "long tails" of several years which require capacities over long periods, their monitoring constitutes a permanent challenge, and are ill-suited to aggregate the results of customers, multi-insured, under construction the incidents listed are difficult to assign, resulting in market consequences that are not well suited to pool systems that aim for maximum pooling. On the other hand, they are well suited to nuclear operating policies, whether nuclear Liability or Property Damage, which are short, renewable contracts, and are well suited to covering a specific site. It then promotes the pooling of risks through the retrocession and facilitate the mutualization.

3.3.2. Open policies

a) Positive aspects for SMR risks

It allows results to be checked by the different parties, customers, insurers and reinsurers, and responds to a specific request.

It also allows rapid intervention by the pools and the setting up of hedges already concluded, and the placement already carried out, it is much better suited to SMRs, because in fact the construction contracts being much shorter, it is necessary to anticipate and avoid updates which can be long in terms of exchanges. It can be adapted to different insurance products, property, liability, it allows to obtain a program dedicated to a fleet, on a region comprising several countries. Risk control, prevention programs are facilitated. The open policies can also propose a multiline solution to allow a global alternative for a serial production.

b) Negative aspects for SMR risks

It is necessary to plan the main developments, the insurers must be associated upfront in order to better understand the risks.

The protocol must be simple and effective, it must contain the necessary insurance products and meet expectations based on deductibles and limits. The price must make it possible to anticipate a balance over several years, and insurers must commit upstream.

The content must be flexible enough to allow for activation of sub-policies and partnerships in the planned SMR development countries. and the intervention of local structures.

4. CONCLUSION

SMRs are small reactors with variable, integrated and standardized engineering. They exist in the form of several technologies, some of which can be directly adapted to power generation or energy-consuming industrial processes. Produced in a modular fashion in the factory, their installation then requires much less civil engineering work. They thus offer significant prospects in terms of cost reductions and construction times. Their size allows them to benefit from size effects to maintain essentially passive security systems.
On the other hand, SMRs factories can only be made profitable if their order book permit a substitution of the standard effect of scale used so far in the nuclear power industry by the effect of series.

The possibility of building a power generation unit in stages, allows a faster return on investment and a reduction in project costs, associated with a lower exposure to economic risk.
The ease of installation, on land but also on a barge, allows them to be located on sites with little infrastructure, for example near mines or even in developing countries where the electricity network is not developed, giving access to decarbonized energy. Specific uses, particularly in industry, would be possible with some of these reactors, making it possible to decarbonize these industrial processes. The developments to come in the next few years will make it possible to validate or not certain applications allowing an energy mix in sectors with high energy consumption in particular chemistry and hydrogen production.
The classification of the different types of SMR-reactors makes it possible to anticipate different routes in terms of insurance, by isolating the devices requiring nuclear risk cover adaptations such as micro SMRs. Insurance products exist to deal with this new challenge. Maybe for some SMRs partial adaptations of operating methods between companies and nuclear pools are to be expected, as well as anticipation, partnerships to accelerate the methods of the insurance sector and take the industrial train.
The insurance products to be provided remain consistent with what currently exists for large units, the clauses which are driving the bridge between conventional covers and nuclear covers are applicable with for some items (HRZ, reactor), clear definitions are necessary to well understand clauses such as NMA 1975 (a).
Modification of the durations of coverages and the positioning of the dates of implementation of the various policies in comparison with large installations, for the transport part as example, or for nuclear liability of the operator will have to be expected. In this respect, pre-programmed multi-line protocols could represent the solutions to meet the challenges of reducing implementation times.
An adaptation of nuclear risk studies for the transition from single big unit to the manufacture of small series of finished products is necessary, whether in terms of mastery of manufacturing processes, emerging or cybernetic risks, for example.

The community of nuclear insurers and reinsurers, the pools, have the necessary tools to deal with this technological development, continue their missions and support customers in this energy sector and development of carbon-free industries which are essential with regard to the total consumption of electrical energy. However, it will be necessary to remain vigilant, to anticipate any difficulties and obstacles with the help of companies and their clients to propose solutions in the time allowed to provide the necessary support for the development and implementation of this equipment.

APPENDIX

1. TOP 10 QUERIES WHICH SHOULD BE ANSWERED FOR THE UNDERWRITER

In this appendix we summarize the main questions the underwriter shall answer or elements which should be defined during the underwriting process of the insurance for the SMRs.

1. Definition of the site in the policy wording
2. Understanding of the manufacturer guarantee and the concerned scope
3. Definition of the Insured
4. On site expected activities
5. When and where the fuel is loaded?
6. HRZ boundaries
7. Nature of the boiler design, (proven or unproven)
8. References
9. Environment and neighborhood of the SMR, consequential perils
10. SMR part, Policy required cover: How to get access/ to replace/ to repair? Administrative costs (restart after stoppage, with or without damage)?
11. Acceptance procedure of the SMR on final site after transportation
12. Usual raw materials? QA, QC?
13. Accessibility and repair works on site?
14. DSU questions, who is covered and what is covered?
15. Exclude DSU on nuclear cover
16. Serial loss clause?
17. What become SMR in case of major nuclear event?

2. RISK MATRIX

Coolant outlet Temperature	Type	Coolant	Fuel	Moderator	Uses	Maturity level (*)	MPL SCENARIO FOR THE CONCERNED ASSOCIATION		EAR/CAR	DSU	Hot Testing/MB/Property	BI	Fuel loaded at manufacturers premises?	Areas of concern - conventional construction cover	Areas of concern - hot testing and MB/Property cover	RECOMMANDATIONS & PROPOSALS
Thermal Neutron							Nuclear island	From concerned Activity on nuclear island	Location type							Clauses sublimits and recommendations
280-300°C	BWR	Boiling water	Uranium oxide	Light water	- District heating (co-generation)	Gen III	According to SMR size, melting of the core	Osmosis/boiling processes, no major perils on nuclear island		Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted, method of using of the reactor, (base, pick, stop & go)	Serial clause - Design clause- No BI on Nuclear risk (to much incertanties)
					- Power generation		Contamination of the equipment in the vicinity	Fire from ST zone		Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted, method of using of the reactor, (base, pick, stop & go)	Serial clause - Design clause- No BI on Nuclear risk (to much incertanties)
300-350°C	PWR	Pressurized water	Uranium oxide	Light water	- Desalination	Gen III	According to SMR size melting of the core	Osmosis/boiling processes, no major perils on nuclear island		Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted, method of using of the reactor, (base, pick, stop & go)	Serial clause - Design clause- No BI on Nuclear risk (to much incertanties)
					- Power generation		Contamination of the equipment in the vicinity	Fire from ST zone		Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted, method of using of the reactor, (base, pick, stop & go)	Serial clause - Design clause- No BI on Nuclear risk (to much incertanties)
	HWR	Pressurized heavy water (Candu)	Uranium naturel	Heavy water	- Power generation	*(1) GEN III	According to SMR size melting of the core	Fire from ST zone	Green or Brown site	Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted, method of using of the reactor, (base, pick, stop & go)	Serial clause - Design clause- No BI on Nuclear risk (to much incertanties) Consider NMA 1975 a application,concerning fuel loading and first criticality (heavy water)...
							Contamination of the equipment in the vicinity			Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.		Serial clause - Design clause- No BI on Nuclear risk (to much incertanties) Consider NMA 1975 a application,concerning fuel loading and first criticality (heavy water)...
374-550°C	SCWR	Supercritical water	Uranium oxide	Light water	- Power generation	*GEN IV	Melting of the core Risk of large contamination of the equipment in the vicinity	Fire from ST zone	Green or Brown site	Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted, method of using of the reactor, (base, pick, stop & go)	Serial clause - Design clause- No BI on Nuclear risk (to much incertanties) Pay attention to the live steam pressure Specific fuel to be used (hight temperature resistant)
			Or		- Other miscellaneous industrial uses (pulp and paper, hydrocarbon refining, methanol production, etc.)			Fire from pulp and paper zone, Explosion from refining, methanol production etc...	Green or Brown site	Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc....) or other flammable products influence should be carrefully analysed for risk study.	BI or DSU not recommended - Serial clause Design clause
			Thorium oxide and Plutonium							Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc....) or other flammable products influence should be carrefully analysed for risk study.	
550-700°C	MSR	Molten slats *(Fuel is thinned in the molten salt which, in a liquid form, is the coolant itself)*	Various mixture of salts of [uranium or thorium] and [sodium chloride or lithium fluoride or beryllium fluoride for example], in a liquid state	Graphite	- Power generation	GEN IV	Risk of nuclear fire in case of contact with water Large Contamination of the equipment in the vicinity	Fire from ST zone	Green or Brown site	Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc....) or other flammable products influence should be carrefully analysed for risk study.	Design clause- No DSU BI on Nuclear risk (to much incertanties) Pay attention to the live steam pressure and temperature
					Hydrogen production by methane reforming			**Fire & Explosion from Hydrogen production by methane reforming,**	Green or Brown site	Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc....) or other flammable products influence should be carrefully analysed for risk study.	BI or DSU not recommended - Serial clause Design clause
700-1 000°C	GCR	Helium	Enriched uranium oxide in the form of a pebble bed	Graphite	- Hydrogen production, either by reforming methane, or by gasification of coal (coal gas), or by thermal dissociation of water.	*(2) GEN IV				Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc....) or other flammable products influence should be carrefully analysed for risk study.	Design clause- No DSU BI on Nuclear risk (to much incertanties) Pay attention to the live steam pressure and temperature
	(HTR)		or Uranium oxycarbide in the form of TRISO (tri-isotopic microparticles) included in the core structure itself		- Metallurgy					Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.				Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc....) or other flammable products influence should be carrefully analysed for risk study.	Design clause- No DSU BI on Nuclear risk (to much incertanties) Pay attention to the live steam pressure and temperature

Note 1: For all the above categories using UO2, the enrichment rate often reaches 8 to 10% in order to limit core reloading.
Note 2: The fuels used in FNR are usually either highly enriched or contain Pu, sometimes at high level.

(*) The "M" column assesses the maturity of the technology. In green are proven technologies. In orange (+/- dark) are technologies under development.

(1) India is operating IPHWR 220 reactors.
(2) China is completing the commissioning of the HTR-PM reactor (industrial demonstrator).
(3) The SFR technology was already tested in France, including on an industrial scale (Phénix, Superphénix), but it was abandoned. Russia has also developed the technology and operates the BN600 and BN800 reactors. It is building a BN1200 reactor. China has developed an industrial demonstrator (CEFR), which has been in operation since 2014. Finally, India also has an industrial demonstrator (FTBR).

Fast Neutron*																
550-750°C	SFR	Liquid Sodium	MOX		- Power generation	● *(3)	●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	● Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc….) or other flammable products influence should be carrefully analysed for risk study.	● BI or DSU not recommended - Serial clause Design clause, pay attention to the liquid sodium
			U-Zr ou U-Pu-Zr				●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	● Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc….) or other flammable products influence should be carrefully analysed for risk study.	● BI or DSU not recommended - Serial clause Design clause, pay attention to the liquid sodium
350 to 650°C	LFR	Liquid metal (lead or lead/bismuth)	HE UO_2		- Other miscellaneous industrial uses (pulp and paper, hydrocarbon refining, methanol production, etc.)	●	●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	● Maintenance level should be adapted with the concerned industrial sector. Specific topics such as (H2 etc….) or other flammable products influence should be carrefully analysed for risk study.	● BI or DSU not recommended - Serial clause Design clause, pay attention to the liquid lead
			MOX							● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	●	● BI or DSU not recommended - Serial clause Design clause
			PuN–UN (nitride)							● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.		● BI or DSU not recommended - Serial clause Design clause
550-700°C	MSFR	Molten slats *(Fuel is thinned in the molten salt which, in a liquid form, is the coolant itself)*	Various mixture of salts of [uranium or thorium] and [sodium chloride or lithium fluoride or beryllium fluoride for example], in a liquid state		- Power generation	●	●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	●	● BI or DSU not recommended - Serial clause Design clause
					- Hydrogen production by methane reformation		●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	●	● BI or DSU not recommended - Serial clause Design clause
700-1 000°C	GFR (HTR)	Helium CO2	MOX		- Hydrogen production, either by reforming methane, by gasification of coal (coal gas) or by thermal dissociation of water.		●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	●	● BI or DSU not recommended - Serial clause Design clause
			Uranium oxycarbide		Metallurgy		●	●	●	● Extended repair timescales due to sourcing exotic materials. Delays caused by legislative reviews, decontamination delays, transport delay if modules are returned to the OEM.	●	●	●	● Specialist materials, weld quality control. Risk of faulty workmanship. Challenges during movement, transit and erection. Difficulties in accessing inner areas of any module post-fabrication. More expensive repair and access costs.	●	● BI or DSU not recommended - Serial clause Design clause

**Minimum size is a mandatory criteria of design, there is no micro reactors,*

● Red dot, some criteria should be reviewed carrefully

● Green dot, can be treated

● Orange dot, some criteria should be checked

3. REMARKS ON THE MINIMAL LIABILITY AMOUNT PRESCRIBED IN THE CONVENTIONS

The conventions establish minimal requirements in terms of the sum for which operators should be liable in the case of an incident and the obligation for operators to maintain insurance or financial securities to ensure that they will be able to meet the amount of their prescribed liability. The following table gives the operator's liability amounts under the above-mentioned conventions[32]:

OECD Conventions	
RPC	
Maximum liability amount	None
Minimum amount	EUR 700 million
Reduced minimum liability amounts[33]	
Low-risk installation	EUR 70 million
Transport	EUR 80 million
RBSC	
First tier (operator, as under the RPC)	Minimum EUR 700 million
Second tier (installation state)	first tier up to EUR 1.2 billion
Third tier (all Brussels Supplementary Convention states)	EUR 300 million
Total amount available under the RPC and RBSC	**Minimum EUR 1.5 billion**
IAEA Conventions	
VC	
Maximum liability amount	None
Minimum liability amount	
Gold value of USD 35/oz. at 29 Apr. 1963	USD 5 million
Gold value of USD 1835/oz. at 2nd of March 2023	USD 262 million
RVC	
Maximum liability amount	None
Minimum amount	SDR 300 million
Reduced minimum liability amounts[34]	
Low-risk activities	SDR 5 million

32 The table originates from the following publication: Schwartz, J. (2022), "Liability and compensation for third party damage resulting from a nuclear incident", in NEA (ed.), Principles and Practice of International Nuclear Law, OECD Publishing, Paris, p. 443-444. It has been updated to correspond to current values.

33 From the original publication: State guarantees up to the liability amount specified for operators of nuclear installations generally.

34 From the original publication: State guarantees up to SDR 300 million.

CSC	
First tier (operator or operator and installation state)	Minimum SDR 300 million
Reduced minimum liability limit	
Low-risk activities	SDR 5 million
Second tier (all CSC states)	SDR 106 million (as of 2nd of March 2023) SDR 399 million (estimated) if all IAEA member states join.
Total amount available under the CSC	**SDR 406 million (as of 2nd of March 2023)** **SDR 699 million (estimated if all IAEA member states join.**

On the application of the NMA1975 nuclear exclusion clause to factory fuelled SMRs:

When does a factory fuelled SMR begins to fall under the NMA1975 nuclear exclusion clause? The application of the NMA1975 to SMRs will be discussed in chapter 2 of this document. We shortly discuss here the particularity of its application concerning the transport of a factory fuelled SMR. We mentioned that such an SMR would fall into the framework of the nuclear liability conventions as soon as it receives its first fuel load. Is it so for the NMA1975 nuclear exclusion clause? A fuelled SMR in its factory falls under the definition of "Nuclear Reactor"[35] provided by the clause and as such is to be considered as a "Nuclear Installation"[36,37,38] in the clause's framework. Further, the clause defines what "Nuclear Energy" risks are. Under which point (from I to IV) would fall our SMR? Although such SMR and its equipment might be covered by point III and IV, it would be interesting to look at point I and II and see if they might also apply:

I. Refers to "all Property, on the site of a nuclear power station". The words "nuclear power station" are undefined in the text and hence it is unclear if any SMRs once fixed anywhere would not actually become one.

II. Relates to reactors "on any site other than a nuclear power station" with, among others, the intent to cover research reactors. Its wording is probably not adapted when thinking about factory fuelled SMRs. Indeed, such SMRS will (1) probably stay on or become themselves a nuclear power station upon installation in the host country and (2) they will by nature become nuclear reactor (in the meaning of the clause) before being delivered onsite so before being installed on "any site", for example during transport (the word "site" is undefined but implies a fixed installation), and (3) as written above although the words "nuclear power station" are undefined in the text, it is unclear if any SMRs once fixed anywhere would not actually become one.

[35] Even if the SMR is at the beginning for transport purposes not able to sustain any chain process, it "can" potentially sustain such reaction already upon fuelling, even if such sustained reaction only take place in the reactor once it has gone through an internal configuration change upon delivery in the host state.

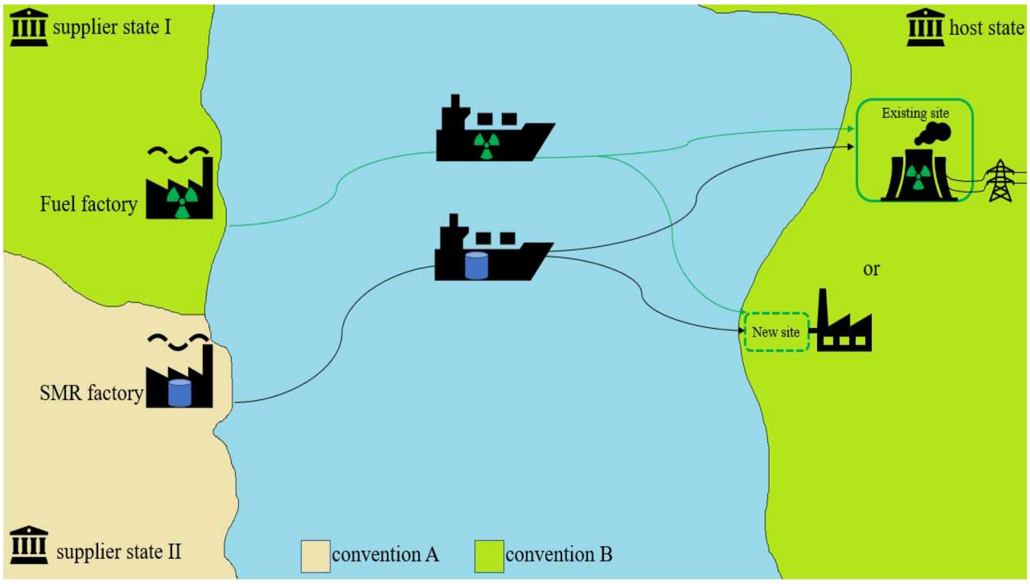
[36] this affirmation won't probably be valid when considering the definition of a "Nuclear Installation" under the nuclear liability conventions.

[37] Most probably in this case the whole SMR, or at least the reactor module transported, due to its design and compactness, will have to be considered as "High Radioactivity Zone or Area" in the meaning of the exclusion clause.

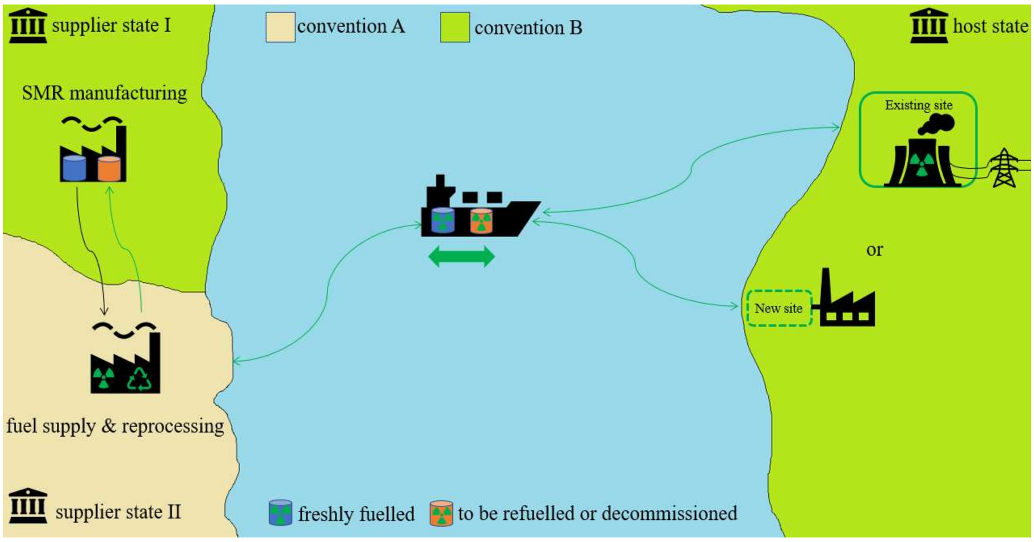
[38] although the "Exposé des motifs" of the clause argues that the definition for nuclear installation is similar to one of the nuclear liability conventions, it is not the case as the definition of the NMA is much larger, allowing for example a fuelled SMR under transport to be classified as a "Nuclear Installation".

So, the question above is probably not to be answered easily. Maybe, the inclusion into the clause of a fuelled SMR under transport as "Nuclear Energy Risks" could be made possible by adding an article mentioning "Nuclear Reactors" only.

Furthermore, article 1(a) and (b) of the clause would equally apply to this SMR, the first of which would apply as soon as "Nuclear Material" is loaded in the SMR to be insured and the second, if the SMR is to be recognized as reactor installation, upon *" fuel loading or first criticality where so agreed with the relevant local Nuclear Insurance Pool and/or Association".* In our base scenario for factory fuelled SMR, we didn't mention the place where the SMR would be "hot tested" and first taken critical, depending on the use case, this might happen in the supplier or in the host state. Either way, no conflict or uncertainty linked to the use of the NMA1975 clause should occur, as the presence or not of "Nuclear Material" in the SMR, as we just saw, is superseding. In conclusion the SMR would fall under the clause upon loading and a precision of the clause to support fuelled SMR under transport (the word "site" implying a fixed state) might be needed.

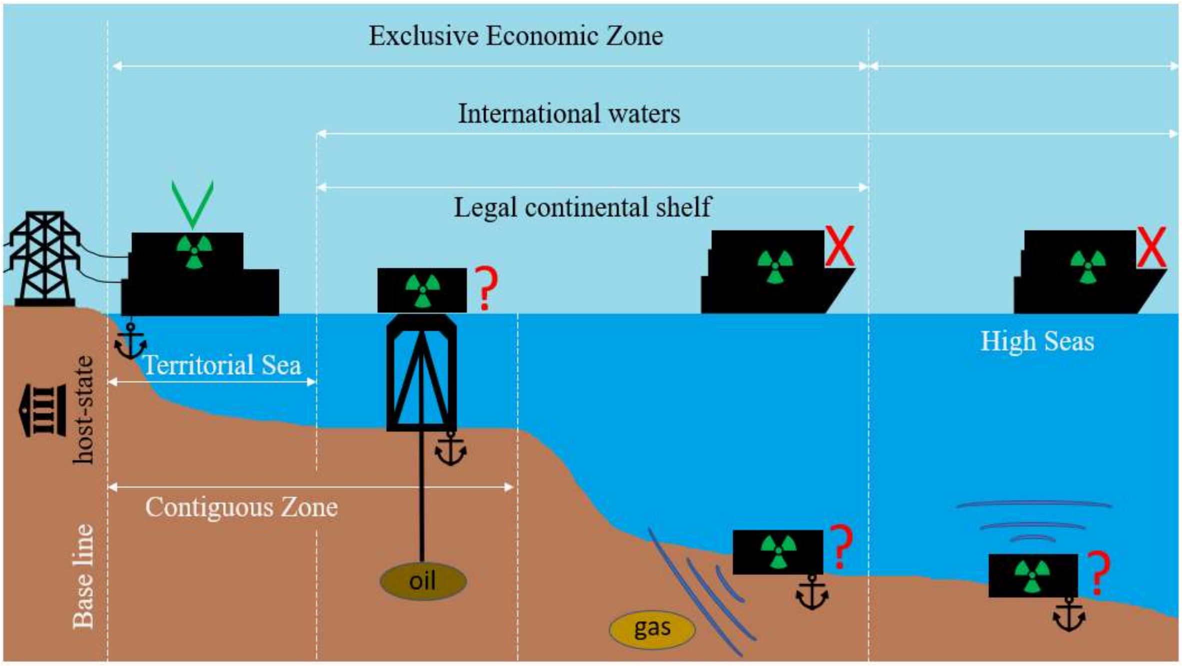


Deployment scheme for fixed land based SMRs[39]



Deployment scheme for factory loaded mobile/fixed SMRs [40]

[39] Radioactive transports are displayed in green, conventional ones in black.
[40] Radioactive transports are displayed in green, conventional ones in black.



Marine-based SMRs and Maritime zones

Note on Figure above: The figure gives different possible use cases of marine-based SMRs but is far from exhaustive, for example the floating SMR given as an illustration on the top right side of the picture might as well be placed in the territorial sea on the left. The figure also attracts the attention to the possibility of SMRs operating outside of the territory of contracting parties. SMRs shown alongside a red cross do not fall under the convention's definition of a "Nuclear Installation", as they are, by nature, not fixed. On the other side, the one shown alongside a question mark would probably not fall under the convention's definition of a "Nuclear Installation" today but their status might still be discussed in the framework of the Vienna conventions. Indeed, one should note that an area where the RPC and the Vienna conventions might conceptually differ, arises in the case of nuclear installations installed outside of the territory of a contracting party, which might happen for these SMRs, for example when deployed in international waters. The Vienna conventions explicitly mention the eventuality of an installation not being "situated within the territory of any State" in their definition of "installation state".[41] Furthermore, the RVC explicitly foresees the possibility for a non-contracting state to possess a nuclear installation in "any maritime zones established by it in accordance with the international law of the sea"[42] , which eventually implies having a nuclear installation outside of its territory. The RPC does not contain a similar definition of an "installation state" and refers, throughout its text, to nuclear installations situated within the territory of a contracting party. The author's interpretation is that, in cases where a factory-fuelled SMR is operated at a fixed place outside the territory of any states, for example, on the surface or the bottom of the sea, in international waters, although no transport is physically taking place during the SMR's operation, the transport as defined in the RPC would have not stopped and liability would have remained with the liable operator during transport. The operation of such an SMR, once fixed, contradicts the conclusion presented earlier regarding nuclear installation under the Paris and Vienna regime, that energy production during transport is excluded and reinforce the assertion made

[41] From [1] and [3] Article I(1)(d): "'Installation State', in relation to a nuclear installation, means the Contracting Party within whose territory that installation is situated or, if it is not situated within the territory of any State, the Contracting Party by which or under the authority of which the nuclear installation is operated."

[42] See [3], Article I A(3)(a).

at the beginning of this note.[43] Since the Vienna Framework through its definition of "installation state" seems to allow for nuclear installation being situated outside of the territory of any state, the above interpretation that a fixed SMR outside of the territory of a contracting party is to be considered as being "in transport" would contradict the concept of a nuclear installation itself which, as already stated, exclude both under the Paris and Vienna regimes the production of energy during transport.

Such use cases might become relevant if marine-based SMRs are to be used in relation to the exploitation of natural resources in a contracting-party's exclusive economic zone (EEZ) or on its continental shelf (as illustrated in previous Figures) in which case they probably would not be considered today as "nuclear installation", first under the Vienna Framework since they would not be attached to the shore by power lines or even anchored to the seabed and second under the RPC for the reason already mentioned above. A relaxation of INLEX's position as already mentioned before might in the framework of the Vienna Convention extend the concept of "Nuclear Installation" to the other SMRs example in Figure if they stay fixed and at no time operate while in transport. Further, the case of such fixed floating SMR anchored to the seabed in the Territorial Sea of a RPC state may also require further analysis, as they might be considered as "Nuclear Installation".

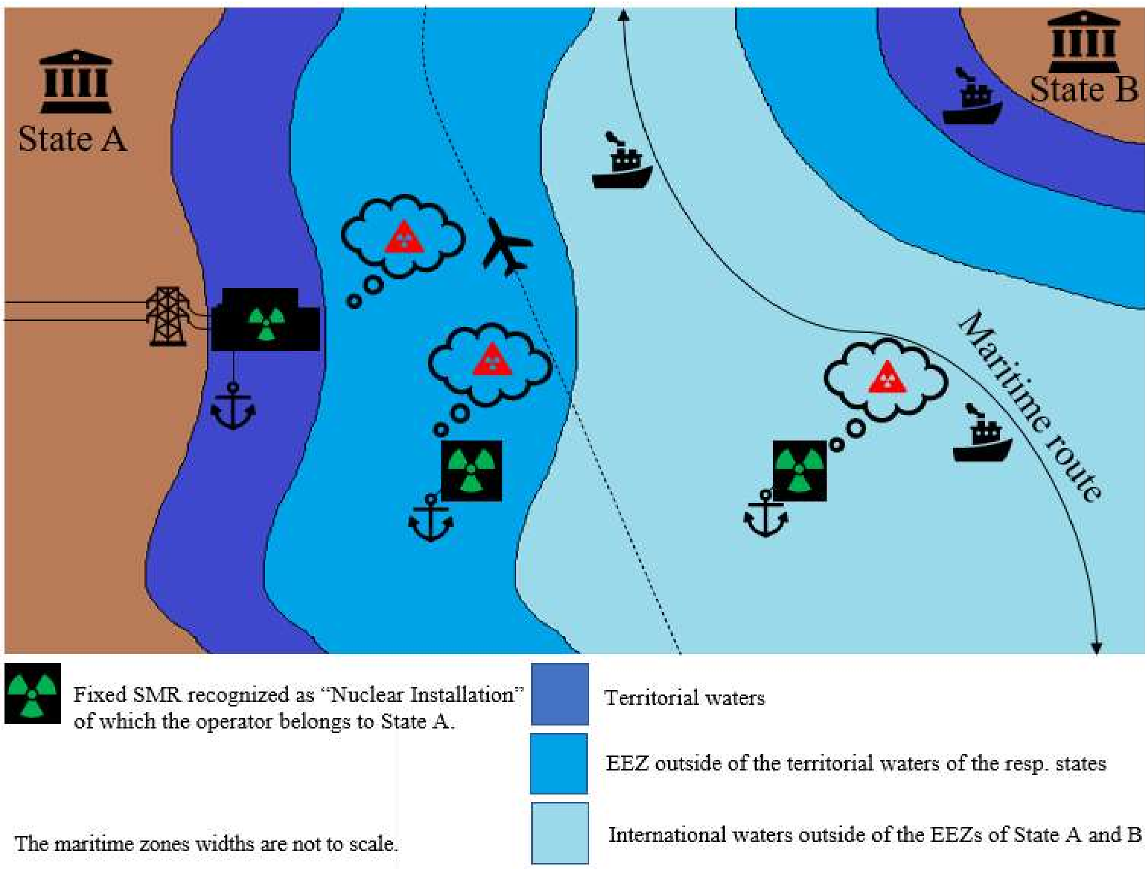


Figure: damage caused by marine-based SMR.

Note on above Figure: The figure shows new configurations that might happen with the deployment of fixed marine-based SMRs, possibly in international waters, and illustrate possible new challenges that might arise when dealing with nuclear damage originating from them. Considering what we said above, the SMR anchored to the seabed and connected to the grid will probably be recognized as "Nuclear Installations" under the conventions, the two other might as well be only recognized as radioactive material under transport belonging to

[43] Indeed, as already mentioned, although no transport physically takes place, the SMR would be in a "transport" state.

the "Nuclear Installation" where they were fuelled and operated by an operator of country A. If both countries A and B aren't parties to the same conventions or possess equivalent nuclear liability legislation and principles, not only the operator of the SMR in the country A might be confronted with legal action outside of its own jurisdictions, which might hinder the feasibility of such scheme.

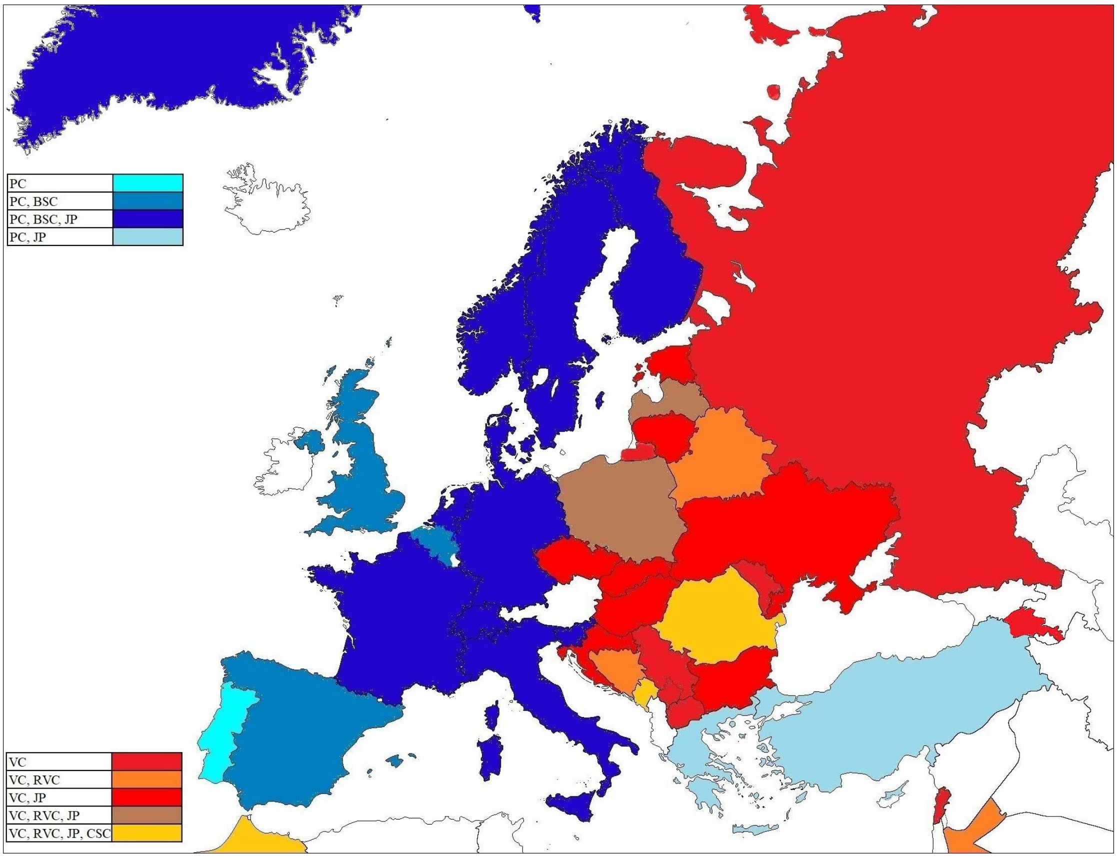


Figure: Spread of the conventions in Europe[44]

[44] Figures use data originating in the following NEA document: NEA (2022), "NUCLEAR OPERATORS" THIRD PARTY LIABILITY AMOUNTS AND FINANCIAL SECURITY LIMITS (Updated June 2022), available at: www.oecd-nea.org/jcms/pl_31866/table-on-nuclear-operators-liability-amounts-and-financial-security-limits-non-official-updated-june-2022.

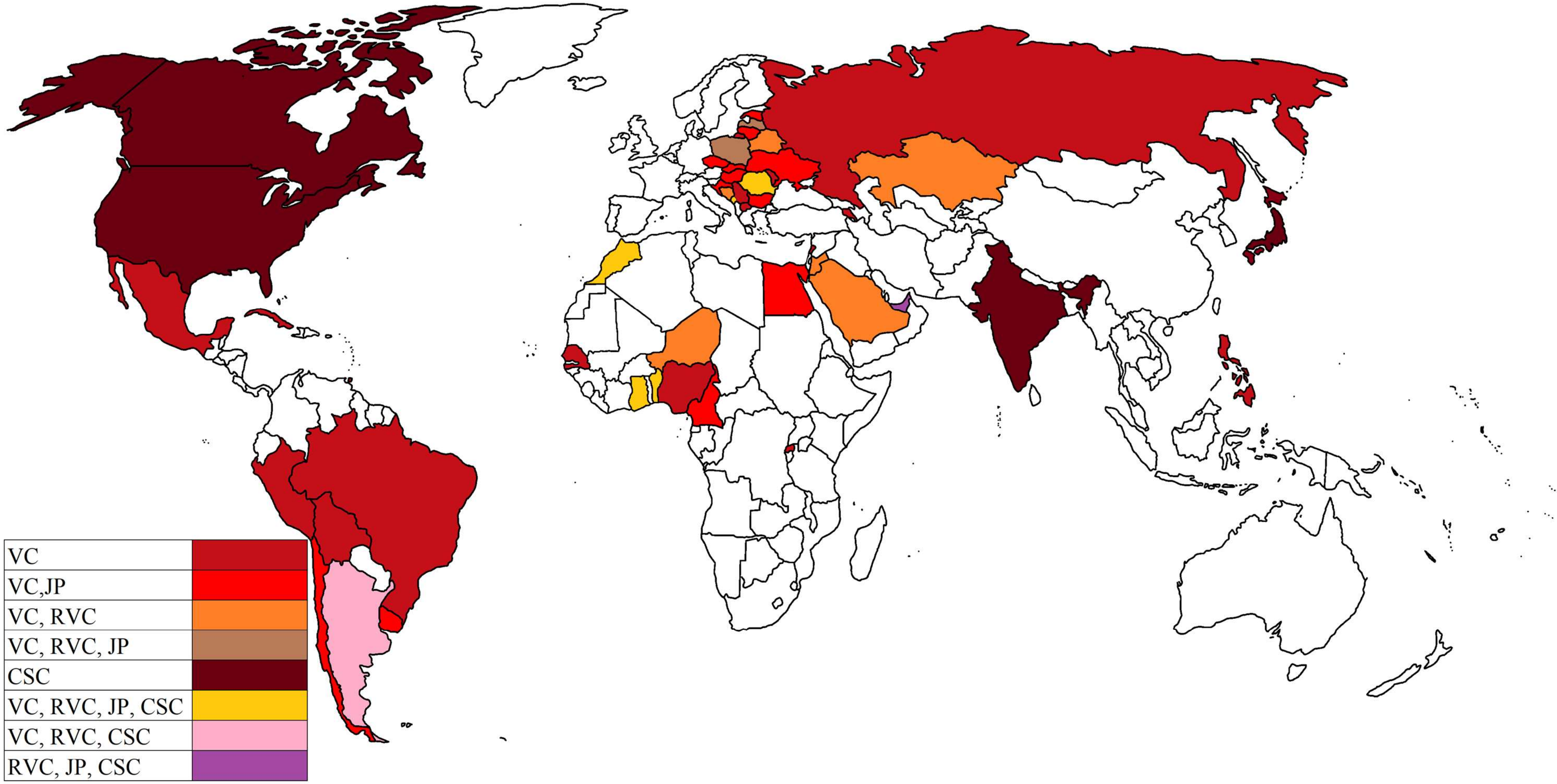


Figure: Spread of the Vienna conventions (incl. CSC)[45]

[45] Figures use data originating in the following NEA document: NEA (2022), "NUCLEAR OPERATORS" THIRD PARTY LIABILITY AMOUNTS AND FINANCIAL SECURITY LIMITS (Updated June 2022), available at: www.oecd-nea.org/jcms/pl_31866/table-on-nuclear-operators-liability-amounts-and-financial-security-limits-non-official-updated-june-2022.

4. NUCLEAR EXCLUSIONS CLAUSES

The use of the NMA 1975 (a) in the conventional contract is subject to a clear definition of the type of SMR, to identify the equipment and its elements positioning in the clause, and a view of the HRZ fixed boundaries limits, (micro SMRs or SMR).

10/3/94 NMA1975(A) - NUCLEAR ENERGY RISKS EXCLUSION CLAUSE (REINSURANCE) (1994) (WORLDWIDE EXCLUDING U.S.A. AND CANADA)

This agreement shall exclude Nuclear Energy Risks whether such risks are written directly and/or by way of reinsurance and/or via Pools and/or Associations.

For all purposes of this agreement Nuclear Energy Risks shall mean **all first party and/or third party insurances or reinsurances (other than Workers' Compensation and Employers' Liability) in respect of**:

I. All **Property,** on the site of a nuclear power station.

Nuclear Reactors, reactor buildings and plant and equipment therein on any site other than a nuclear power station.

II. All **Property**, on any site (including but not limited to the sites referred to in I above) used or having been used for:

- **a.** The generation of nuclear energy; or {Response}
- **b.** The **Production, Use or Storage of Nuclear Material**

III. Any other **Property** eligible for insurance by the relevant local Nuclear Insurance Pool and/or Association but only to the extent of the requirements of that local Pool and/or Association.

IV. The supply of goods and services to any of the sites, described in I to III above, unless such insurances or reinsurances shall exclude the perils of irradiation and contamination by **Nuclear Material**.

Except as undernoted, Nuclear Energy Risks shall not include:

- **i)** any insurance or reinsurance in respect of the construction or erection or installation or replacement or repair or maintenance or decommissioning of **Property** as described in I to III above (including contractors' plant and equipment);
- **ii)** any Machinery Breakdown or other Engineering insurance or reinsurance not coming within the scope of (i) above.

Provided always that such insurance or reinsurance shall exclude the perils or irradiation and contamination by **Nuclear Material**.

However, the above exemption shall not extend to:

1. The provision of any insurance or reinsurance whatsoever in respect of:

a. **Nuclear Material**;

b. Any **Property** in the **High Radioactivity Zone or Area** of any **Nuclear Installation** as from the introduction of **Nuclear Material** or - for reactor installations - as from fuel loading or first criticality where so agreed with the relevant local Nuclear Insurance Pool and/or Association.

2. The provision of any insurance or reinsurance for the undernoted perils:

- ✓ Fire, lightning, explosion;
- ✓ Earthquake;
- ✓ Aircraft and other aerial devices or articles dropped there from;
- ✓ Irradiation and radioactive contamination;
- ✓ Any other peril insured by the relevant local Nuclear Insurance Pool and/or Association;

in respect of any other **Property** not specified in 1 above which directly involves the **Production, Use or Storage of Nuclear Material** as from the introduction of **Nuclear Material** into such **Property**.

DEFINITIONS

"**Nuclear Material**" means:

I. Nuclear fuel, other than natural uranium and depleted uranium, capable of producing energy by a self-sustaining chain process of nuclear fission outside a **Nuclear Reactor**, either alone or in combination with some other material; and

II. **Radioactive Products or Waste**.

"**Radioactive Products or Waste**" means any radioactive material produced in, or any material made radioactive by exposure to the radiation incidental to the production or utilization of nuclear fuel, but does not include radioisotopes which have reached the final stage of fabrication so as to be usable for any scientific, medical, agricultural, commercial or industrial purpose.

"Nuclear Installation" means:

I. Any **Nuclear Reactor**;

II. Any factory using nuclear fuel for the production of **Nuclear Material**, or any factory for the processing of **Nuclear Material**, including any factory for the reprocessing of irradiated nuclear fuel; and

III. Any facility where **Nuclear Material** is stored, other than storage incidental to the carriage of such material.

"**Nuclear Reactor**" means any structure containing nuclear fuel in such an arrangement that a self-sustaining chain process of nuclear fission can occur therein without an additional source of neutrons.

"**Production, Use or Storage of Nuclear Material**" means the production, manufacture, enrichment, conditioning, processing, reprocessing, use, storage, handling and disposal of **Nuclear Material**.

"**Property**" shall mean all land, buildings, structures, plant, equipment, vehicles, contents (including but not limited to liquids and gases) and all materials of whatever description whether fixed or not.

"**High Radioactivity Zone or Area**" means:

i. For nuclear power stations and **Nuclear Reactors**, the vessel or structure which immediately contains the core (including its supports and shrouding) and all the contents thereof, the fuel elements, the control rods and the irradiated fuel store; and

ii. For non-reactor **Nuclear Installations**, any area where the level of radioactivity requires the provision of a biological shield.

01/4/96 NMA1980A - NUCLEAR INCIDENT EXCLUSION CLAUSE-PHYSICAL DAMAGE-REINSURANCE - CANADA

1. This Agreement does not cover any loss or liability accruing to the Reinsured directly or indirectly, and whether as Insurer or Reinsurer, from any Pool of Insurers or Reinsurers formed for the purpose of covering Atomic or Nuclear Energy risks.

2. Without in any way restricting the operation of paragraph 1 of this clause, this Agreement does not cover any loss or liability accruing to the Reinsured, directly or indirectly, and whether as Insurer or Reinsurer, from any insurance against Physical Damage (including business interruption or consequential loss arising out of such Physical Damage) to:

1. Nuclear reactor power plants including all auxiliary property on the site, or
2. Any other nuclear reactor installation, including laboratories handling radioactive materials in connection with reactor installations, and critical facilities as such, or
3. Installations for fabricating complete fuel elements or for processing substantial quantities of radioactive materials, and for reprocessing, salvaging, chemically separating, storing or disposing of spent nuclear fuel or waste materials, or
4. Installations other than those listed in 3 above using substantial quantities of radioactive isotopes or other products of nuclear fission.

3. Without in any way restricting the operation of paragraphs 1 and 2 of this clause, this Agreement does not cover any loss or liability by radioactive contamination accruing to the Reinsured, directly or indirectly, and whether as Insurer or Reinsurer, from any insurance on property which is on the same site as a nuclear reactor power plant or other nuclear installation and which normally would be insured therewith, except that this paragraph 3 shall not operate.

a. Where the Reinsured does not have knowledge of such nuclear reactor power plant or nuclear installation, or

b. Where the said insurance contains a provision excluding coverage for damage to property caused by or resulting from radioactive contamination, however caused.

4. Without in any way restricting the operation of paragraphs 1, 2 and 3 of this clause, this Agreement does not cover any loss or liability by radioactive contamination accruing to the Reinsured, directly or indirectly, and whether as Insurer or Reinsurer, when such radioactive contamination is a named hazard specifically insured against.

5. This clause shall not extend to risks using radioactive isotopes in any form where the nuclear exposure is not considered by the Reinsured to be the primary hazard.

6. The term "radioactive material" means uranium, thorium, plutonium, neptunium, their respective derivatives and compounds, radioactive isotopes of other elements and any other substances which may be designated by or pursuant to any law, act or statute, or any law amendatory thereof as being prescribed substances capable of releasing atomic energy, or as being requisite for the production, use or application of atomic energy.

7. Reinsured to be sole judge of what constitutes:

    a. substantial quantities, and

    b. the extent of installation, plant or site.

8. Without in any way restricting the operation of paragraphs 1, 2, 3 and 4 of this clause, this Agreement does not cover any loss or liability accruing to the Reinsured, directly or indirectly, and whether as Insurer or Reinsurer caused:

    a. by any nuclear incident as defined in or pursuant to the Nuclear Liability Act or any other nuclear liability act, law or statute, or any law amendatory thereof, or nuclear explosion, except for ensuing loss or damage which results directly from fire, lightning or explosion of natural, coal or manufactured gas;

    b. by contamination by radioactive material.

U.S.A.

12/12/57 NMA1119 - NUCLEAR INCIDENT EXCLUSION CLAUSE-PHYSICAL DAMAGE - REINSURANCE

1. This Reinsurance does not cover any loss or liability accruing to the Reassured, directly or indirectly and whether as Insurer or Reinsurer, from any Pool of Insurers or Reinsurers formed for the purpose of covering Atomic or Nuclear Energy risks.

2. Without in any way restricting the operation of paragraph (1) of this Clause, this Reinsurance does not cover any loss or liability accruing to the Reassured, directly or indirectly and whether as Insurer or Reinsurer, from any insurance against Physical Damage (including business
interruption or consequential loss arising out of such Physical Damage) to:

    I. Nuclear reactor power plants including all auxiliary property on the site, or

    II. Any other nuclear reactor installation, including laboratories handling radioactive materials in connection with reactor installations, and "critical facilities" as such, or

    III. Installations for fabricating complete fuel elements or for processing substantial quantities of "special nuclear material", and for reprocessing, salvaging, chemically separating, storing or disposing of "spent" nuclear fuel or waste materials, or

    IV. Installations other than those listed in paragraph (2) III above using substantial quantities of radioactive isotopes or other products of nuclear fission.

3. Without in any way restricting the operations of paragraphs (1) and (2) hereof, this Reinsurance does not cover any loss or liability by radioactive contamination accruing to the Reassured, directly or indirectly, and whether as Insurer or Reinsurer, from any insurance on property which is on the same site as a nuclear reactor power plant or other nuclear installation and which normally would be insured therewith except that this paragraph (3) shall not operate

   a. where Reassured does not have knowledge of such nuclear reactor power plant or nuclear installation, or

   b. where said insurance contains a provision excluding coverage for damage to property caused by or resulting from radioactive contamination, however caused. However on and after 1st January 1960 this sub-paragraph (b) shall only apply provided the said radioactive contamination exclusion provision has been approved by the Governmental Authority having jurisdiction thereof.

4. Without in any way restricting the operations of paragraphs (1), (2) and (3) hereof, this Reinsurance does not cover any loss or liability by radioactive contamination accruing to the Reassured, directly or indirectly, and whether as Insurer or Reinsurer, when such radioactive contamination is a named hazard specifically insured against.

5. It is understood and agreed that this Clause shall not extend to risks using radioactive isotopes in any form where the nuclear exposure is not considered by the Reassured to be the primary hazard.

6. The term "special nuclear material" shall have the meaning given it in the Atomic Energy Act of 1954 or by any law amendatory thereof.

7. Reassured to be sole judge of what constitutes:

   a. substantial quantities, and

   b. the extent of installation, plant or site.

Note - Without in any way restricting the operation of paragraph (1) hereof, it is understood and agreed that

   a. all policies issued by the Reassured on or before 31st December 1957 shall be free from the application of the other provisions of this Clause until expiry date or 31st December 1960 whichever first occurs whereupon all the provisions of this Clause shall apply.

   b. with respect to any risk located in Canada policies issued by the Reassured on or before 31st December 1958 shall be free from the application of the other provisions of this Clause until expiry date or 31st December 1960 whichever first occurs whereupon all the provisions of this Clause shall apply.

29/10/59 NMA1251 - NUCLEAR INCIDENT EXCLUSION CLAUSE - PHYSICAL DAMAGE AND LIABILITY (BOILER AND MACHINERY POLICIES) REINSURANCE

1. This reinsurance does not cover any loss or liability accruing to the Reassured as a member of, or subscriber to, any association of insurers or reinsurers formed for the purpose of covering nuclear energy risks or as a direct or indirect reinsurer of any such member, subscriber or association.
2. Without in any way restricting the operation of paragraph 1 of this Clause it is understood and agreed that for all purposes of this reinsurance all original Boiler and Machinery Insurance or Reinsurance contracts of the Reassured shall be deemed to include the following provisions of this paragraph;

   This Policy does not apply to loss, whether it be direct or indirect, proximate or remote:

   a. from an Accident caused directly or indirectly by nuclear reaction, nuclear radiation or radioactive contamination, all whether controlled or uncontrolled; or
   b. from nuclear reaction, nuclear radiation or radioactive contamination, all whether controlled or uncontrolled, caused directly or indirectly by, contributed to or aggravated by an Accident.
3. However, it is agreed that loss arising out of the use of Radioactive Isotopes in any form is not hereby excluded from reinsurance protection.
4. Without in any way restricting the operation of paragraph 1 hereof, it is understood and agreed that policies issued by the Reassured effective on or before 31st December, 1958, shall be free from the application of the other provision of this Clause until expiry date or 31st December, 1961, whichever first occurs, whereupon all the provisions of this Clause shall apply.

23/6/58 NMA1166 - NUCLEAR INCIDENT EXCLUSION CLAUSE-PHYSICAL DAMAGE AND LIABILITY (BOILER AND MACHINERY POLICIES) - REINSURANCE (U.S.A.)

1. This reinsurance does not cover any loss or liability accruing to the Reassured as a member of, or subscriber to, any association of insurers or reinsurers formed for the purpose of covering nuclear energy risks or as a direct or indirect reinsurer of any such member, subscriber or association.
2. Without in any way restricting the operation of paragraph 1 of this Clause it is understood and agreed that for all purposes of this reinsurance all original Boiler and Machinery Insurance or Reinsurance contracts of the Reassured shall be deemed to include the following provisions of this paragraph;

   This Policy does not apply to "loss", whether it be direct or indirect, proximate or remote

   a. from an Accident caused directly or indirectly by nuclear reaction, nuclear radiation or radioactive contamination, all whether controlled or uncontrolled; or

b. from nuclear reaction, nuclear radiation or radioactive contamination, all whether controlled or uncontrolled, caused directly or indirectly by, contributed to or aggravated by an Accident.

3. However, it is agreed that loss arising out of the use of Radioactive Isotopes in any form is not hereby excluded from reinsurance protection.

4. Without in any way restricting the operation of paragraph 1 hereof, it is understood and agreed that

   a. all policies issued by the Reassured effective on or before 30th April, 1958, shall be free from the application of the other provisions of this Clause until expiry date or 30th April, 1961, whichever first occurs, whereupon all the provisions of this Clause shall apply,

   b. with respect to any risk located in Canada policies issued by the Reassured effective on or before 30th June, 1958, shall be free from the application of the other provisions of this Clause until expiry date or 30th June, 1961, whichever first occurs, whereupon all the provisions of this Clause shall apply.

5. REFERENCES

- ⇨ *Publication AIEA 2020 « Advances in Small Modular Reactor technology developments »*
- ⇨ *Conference SFEN du 03/12/2020*
- ⇨ *Publication AIEA 2022 Supplement to: « Advances in Small Modular Reactor technology developments »*
- ⇨ *Nuclear Energy Agency OCDE 2023 "The NEA Small Modular Reactor Dashboard"*
- ⇨ *Conference Nuclear Engineering International Small & Advanced Reactors Virtual Event 18/02/2021*
- ⇨ *Rapport de la Cour Des Comptes Française « Couts de la filière électronucléaire » Janvier 2012*
- ⇨ *IAEA Factory-Fuelled SMR Consultants' Meeting Vienna 13-17 June 2016*
- ⇨ *IAEA Board of Governors General Conference 17 July 2019 (INTEX)*
- ⇨ *Small Modular Reactors - Key to Future Nuclear Power Generation in the U.S Robert Rosner and Stephen Goldberg Energy Policy Institute at Chicago The Harris School of Public Policy Studies*
- ⇨ *Advances in Small Modular Reactors Technology Developments A supplement to IAEA Advanced Reactors Information Systems (ARIS) 2020 Edition*
- ⇨ Small Modular Reactors: Challenges and Opportunities*, OECD 2021 NEA No. 7560 NUCLEAR ENERGY AGENCY ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT*
- ⇨ *Convention on Third Party Liability in the Field of Nuclear Energy of 29 July 1960, as amended by the Additional Protocol of 28 January 1964 and by the Protocol of 16 November 1982 (1960), available at: www.oecd-nea.org/law/paris- convention.html*
- ⇨ ***Paris Convention**, Protocol to Amend the Convention on Third Party Liability in the Field of Nuclear Energy of 29 July1960, as amended by the Additional Protocol of 28 January 1964 and by the Protocol of 16 November1982 (2004) (not yet in force), available at: www.oecd-nea.org/law/paris-convention-protocol.html*
- ⇨ ***Vienna Convention** on Civil Liability for Nuclear Damage (1963), IAEA Doc. INFCIRC/500, 1063UNTS 266.*
- ⇨ ***Protocol to Amend the 1963 Vienna Convention** on Civil Liability for Nuclear Damage (1997), IAEA Doc. INFCIRC/566, 2241 UNTS 302*
- ⇨ *Convention on Supplementary Compensation for Nuclear Damage (1997), IAEA Doc. INFCIRC/567, 36 ILM 1473*
- ⇨ *Extract of the definition of "nuclear installation" under the **Paris Convention**, which is similar to the one provided under other nuclear third party liability conventions. The Revised Explanatory Texts of the Vienna Convention and the CSC stated in the past that the Vienna Convention relates exclusively to land-based nuclear installations; however, this has been rectified in its 2020 version [IAEA International Law Series No. 3 (Rev. 2)]. For more information on low-risk installations under the nuclear liability conventions, see*

paragraph 43 of the Exposé des Motifs of the Paris Convention, paragraphs 68 and 69 of the Exposé des Motifs of the revised Paris Convention [NEA/NLC/DOC(2020)1/FINAL] and pages 43 and 46 of the Explanatory Texts of the revised Vienna Convention and the CSC [IAEA International Law Series No. 3 (Rev. 2)]

- *The NEA has made a table publicly available that aims to gather information on the amounts available to compensate potential victims of a nuclear incident in countries and economies having nuclear power plants and/or having ratified at least one of the international conventions on nuclear third party liability. The table is available at: www.oecd-nea.org/law/table-liability-coverage-limits.pdf; www.oecd-nea.org/upload/docs/application/pdf/2020- 11/2020.10_operators_liability_amount_table_general_final_clean_v2_2020-11-10_09-01-46_808.pdf*
- *LEGAL FRAMEWORKSMALL MODULAR REACTORS: CHALLENGES AND OPPORTUNITIES, NEA No. 7560, © OECD 2021*
- *IMIA WGP 75 (12) from Rio Conference*
- *"Analysis of the potential applicability of the existing nuclear liability conventions to different type of small modular reactors currently under development" by Vincent Jérome H. Roland 2022*
- [1] Vienna Convention on Civil Liability for Nuclear Damage (1963), IAEA Doc. INFCIRC/500, 1063 UNTS 266, entered into force 12 Nov. 1977 (Vienna Convention)
- [2] IAEA (2020), *The 1997 Vienna Convention on Civil Liability for Nuclear Damage and the 1997 Convention on Supplementary Compensation for Nuclear Damage – Explanatory Texts*, IAEA International Law Series, No. 3 (Rev. 2), IAEA Doc. STI/PUB/1906, IAEA, Vienna
- [3] Consolidated text of the Vienna Convention on Civil Liability for Nuclear Damage of 21 May 1963 as amended by the Protocol of 12 September 1997, the so-called "1997 Vienna Convention on Civil Liability for Nuclear Damage", which is included as an Annex to [2], pp. 123-136
- [4] Convention on Third Party Liability in the Field of Nuclear Energy of 29 July 1960, as amended by the Additional Protocol of 28 January 1964, by the Protocol of 16 November 1982, and by the Protocol of 12 February 2004, entered into force 1 Jan. 2022, unofficial consolidated text available at: NEA (2017), "Convention on Third Party Liability in the Field of Nuclear Energy of 29 July 1960, as amended by the Additional Protocol of 28 January 1964, by the Protocol of 16 November 1982 and by the Protocol of 12 February 2004", NEA Doc. NEA/NLC/DOC(2017)5/FINAL (Revised Paris Convention)
- [5] NEA (2020), "Exposé des Motifs of the Paris Convention as amended by the Protocols of 1964, 1982 and 2004", adopted by the Contracting Parties to the Paris Convention on 18 Nov. 2016, NEA Doc. NEA/NLC/DOC (2020)1/FINAL
- [6] Convention of 31 January 1963 Supplementary to the Paris Convention of 29 July 1960, as amended by the Additional Protocol of 28 January 1964, by the Protocol of 16 November 1982 and by the Protocol of 12 February 2004, entered into force 1 Jan. 2022, unofficial consolidated text available at: NEA (2017), "Convention of 31 January 1963 Supplementary to the Paris Convention of 29 July 1960, as amended by the Additional Protocol of 28 January 1964, by the Protocol of 16 November 1982 and by the Protocol of 12 February 2004", NEA Doc. NEA/NLC/DOC(2017)6/FINAL (Revised Brussels Supplementary Convention)
- [7] Convention on Supplementary Compensation for Nuclear Damage (1997), IAEA Doc. INFCIRC/567, 36 ILM 1473, entered into force 15 Apr. 2015 (CSC)

⇨ [8] Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention (1988), IAEA Doc. INFCIRC/402, 1672 UNTS 293, entered into force 27 Apr. 1992 (Joint Protocol)

⇨ [9] NEA (2020), “Exposé des Motifs of the Brussels Supplementary Convention as amended by the Protocols of 1964, 1982 and 2004”, adopted by the Contracting Parties to the Brussels Supplementary Convention on 23 Dec. 2010, NEA Doc. NEA/NLC/DOC (2017)4/FINAL