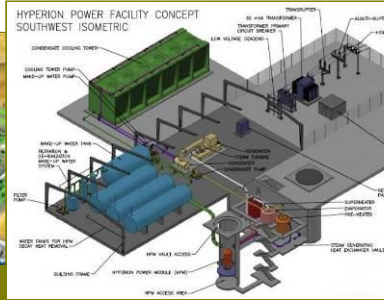
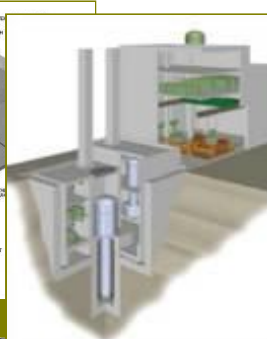




SMART



Hyperion



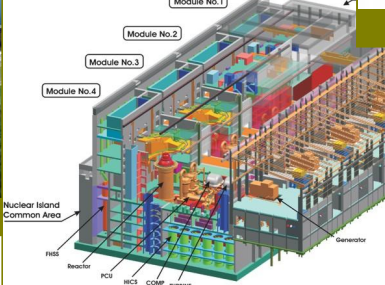
4S



KLT-40S



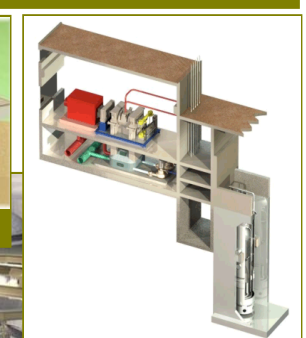
HTR-PM



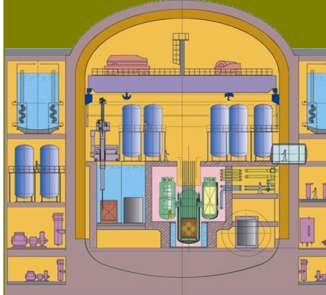
PBMR



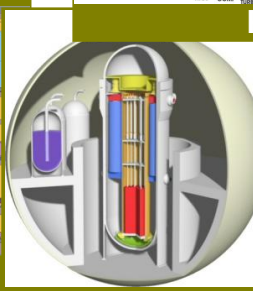
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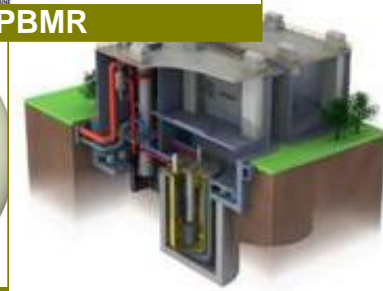
NuScale



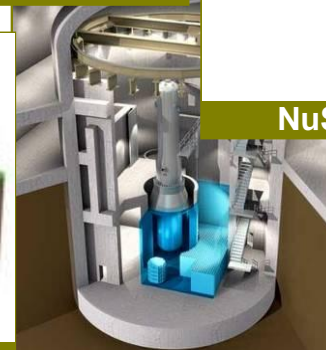
VBER-300



IRIS



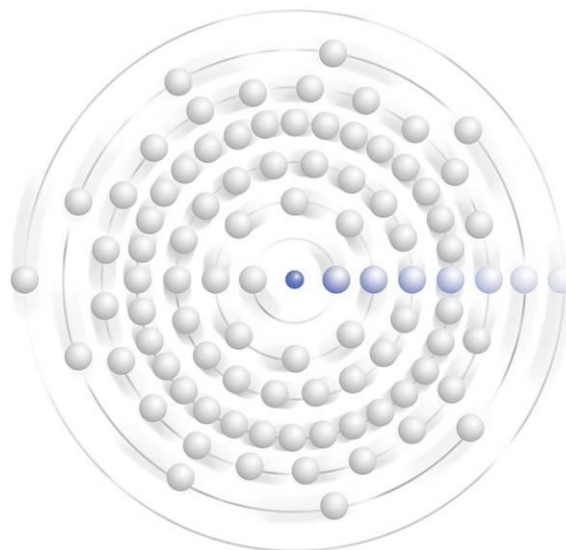
PRISM



mPower



## Small Modular Reactor Assessments



A service of



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# 1 – Introduction & Overview

Small Modular Reactors or SMRs, producing between 10 MWe and 300 MWe, are not a new idea. The first ever nuclear reactors built to produce electricity were of the “small” variety. Even while the majority of the nuclear industry turned towards larger and larger reactor designs, there have always been some strong believers in the smaller designs as well. However, in the past several years, SMRs have gained tremendous attention and renewed energy in the nuclear power world, and this sector has emerged as an important new element of the global nuclear renaissance. For some companies, the SMR offers a brand new opportunity to engage with nuclear power, whereas others see the SMR as a response to the challenges that plague larger reactor designs. Of course, the reactor market is not a “zero-sum game,” and there is room for both large and small reactors in this world. SMRs may in fact provide unique benefits that no other reactor concept can offer. Still, the SMR sector is much less developed than the traditional reactor market.

Although few actual projects for small reactor deployment exist today, many SMR designs are being proposed by both established as well as new, startup nuclear power companies. There are many reasons for this revival of the small reactor concept, especially of the factory-assembled, modular variety; however, there are also a number of unique hurdles for SMRs. The development of a new, emerging SMR industry brings up a number of questions, including:

- What are the primary drivers pushing SMRs forward?
- What are the challenges to SMR development, and how can these be overcome?
- Which companies and designs present the most promising options within the SMR market, and why?
- Who will build these SMRs and where?
- Is the SMR concept viable in the long-term?

This new UxC comprehensive special report responds to these numerous questions while providing an all-inclusive SMR guide for any interested party. Ultimately, this report’s objective is to offer technical, economic, and other commercial assessments of each of the SMR designs being developed in the world today. In addition, the report provides an in-depth discussion of the broader issues impacting SMRs, such as the keys to successful deployment for SMRs, comparisons with larger reactor technologies, specific applications for SMRs, and the broader issues facing potential customers for SMRs.

Based on our extensive research, UxC’s SMRA report is meant as an independent, unbiased assessment of all the likely SMR technologies as well as to provide unique perspectives on the overall small reactor sector. As such, the report does not choose “winners & losers” and leaves it to the reader to make conclusions from our analysis.

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## Target Audience

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The SMR market is still evolving. To our knowledge, no independent comparative analyses of the competing designs exist, and this report aims to fill this information gap. Potential uses for this study include:

- Nations considering a small reactor-based nuclear power program can use this report to evaluate the global offering of SMRs and to better understand the unique issues presented by SMR development.
- Electric power utilities looking to build or expand nuclear capacity may use this report when considering whether the option to go with an SMR is the better fit.
- For those in the financial community considering investing in nuclear power, this report presents crucial perspectives on the overall prospects for SMRs as well as insights on which companies may fare better in the SMR race.
- Manufacturing and supply chain companies interested in expanding their customer base through SMR projects can gain new insights.
- Nuclear fuel suppliers eager for a new customer base from SMRs will be better informed.
- Government agencies, regulatory bodies, trade associations, and research organizations can become more educated on SMRs.

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## Qualifying Statements

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At the outset, it is important to highlight the limitations inherent in this type of study and approaches used by UxC to handle them. First, as indicated above, the primary purpose of this report is to provide new and unique perspectives on the SMR market. This is first and foremost an analytical report, as opposed to some of the broader public reports on this same topic. As such, this report is not meant to duplicate the expansive work done by organizations like the IAEA, DOE, NRC, ANS, and others, who fill important roles in promoting or describing SMR technologies.

Secondly, UxC made a decision when beginning this project to base the analysis in this report on public data, as opposed to requesting information from the various vendors of SMR designs. The primary reason for this has been to allow UxC to remain independent, unbiased, and fair, since opening the door to direct input by the SMR vendors necessarily would lead to variations in the depth of coverage of designs due to the different amount and type of information that would be made available by each company/organization. Some SMR designers may choose to be very forthcoming with us, while others may decide to not interact at all. To avoid this discrepancy, we decided to go with public information, which for most designs is still extremely rich in content and technical depth – especially through such documents as filings with the U.S. Nuclear Regulatory Commission (NRC).

As described already, the intent of this SMRA report is to provide thorough and critical analysis. In doing so, the purpose is not to diminish any company or organization's efforts in deploying SMRs, but rather to highlight areas that may need further work or analysis. Still, given UxC's position as independent consultancy, we see no reason to "hold our punches" or not point out clear discrepancies or issues with specific SMR designs when we see them.

Finally, we acknowledge at the outset that certain answers to questions on SMRs may not be covered even in the 500+ pages in this report. In some instances, information or analysis has been withheld purposefully to allow for an even level of coverage of the different SMR designs. In addition, given the newness of the market and the fact that it is continuously evolving, many questions remain unanswered, and even with our extensive efforts in researching and ferreting out information on different SMRs, there are still a number of open items. However, a major purpose of this report is to provide a frame of reference by which information that becomes subsequently available can be evaluated and incorporated into understanding the small reactor market and potential going forward.

Thus, while UxC's *Small Modular Reactor Assessments* (SMRA) special report may be seen as a groundbreaking study on this rapidly developing SMR market, we are confident that this report is only assessing the first chapter in the new history of this industry. UxC has dedicated significant resources, time, and energy into this study over the past year, relying on a broad network of experts in all of the disciplines required for these types of full spectrum reactor assessments. We are developing further in-depth analyses on selected topics for these designs, as well as ranking methodologies for future comparisons among various designs. Given the depth of knowledge in the company on SMRs, we stand ready to provide even more detailed assessments on SMR designs in the future – either through updates to this public report or on an individual client basis.

## Structure of Report

In order to best address the points identified above, this report has been organized in three main parts. The first provides an overview and introduction to the overall SMR market. The second analyzes each of the 12 selected SMR designs in detail and offers UxC's independent assessments of the pros and cons of each as well as their prospects for deployment. The third part of this report looks at the next steps for SMR deployment from both a supplier and customer perspective and rounds out the discussion with broader conclusions about the future of the SMR market.

In addition to this **Chapter 1 – Introduction & Overview**, individual chapters in each of these parts are included as follows:

- **Part 1: SMR Market Overview**

**Chapter 2 – SMR's Past and Present** provides the historical context for SMRs and introduces the main reasons for the more recent resurgence of interest in SMRs.

**Chapter 3 – Advantages and Challenges for SMRs** reviews the main positive and negative aspects of SMRs in general (without specifics on different designs).

**Chapter 4 – SMR Economics** analyzes the economic case for SMRs and how their costs stack up with larger nuclear power plants.

- **Part 2: Individual SMR Design Evaluations**

**Chapter 5 – SMR Detailed Assessments Overview** provides the introduction to UxC's analysis of the selected 12 leading SMRs extensively covered in this report. The list of the selected SMR designs is shown in Table 1 (below).

Table 1. Current 12 Leading Global SMR Designs				
Design	Company	Country	Type	MWe (net)
IRIS	Westinghouse	U.S.	PWR	335
mPower	Babcock & Wilcox	U.S.	PWR	125
NuScale	NuScale Power Inc.	U.S.	PWR	45
SMART	KAERI	South Korea	PWR	100
KLT-40S	OKBM Afrikantov	Russia	PWR	35
VBER-300	OKBM Afrikantov	Russia	PWR	295
PBMR	PBMR (Pty) Ltd.	South Africa	HTR	165
HTR-PM	Tsinghua INET & Huaneng	China	HTR	210
GT-MHR	General Atomics	U.S.	HTR	286
4S	Toshiba	Japan	LMR	10
HPM	Hyperion Power Generation	U.S.	LMR	25
PRISM	General Electric-Hitachi	U.S.	LMR	311

**Chapter 6 – PWR-type SMRs** includes in-depth analysis (20-40 pages per design) of the six leading SMRs that use Pressurized Water Reactor (PWR) technologies.

**Chapter 7 – HTR-type SMRs** includes in-depth analysis (20-40 pages per design) of the three leading SMRs that use High Temperature Reactor (HTR) technologies.

**Chapter 8 – LMR-type SMRs** includes in-depth analysis (20-40 pages per design) of the three leading SMRs that use Liquid Metal Reactor (LMR) technologies.

Since there are many more than just 12 SMR designs being considered around the world, **Chapter 9 – Additional SMR Designs** includes descriptions and basic analysis of over 40 additional SMRs beyond the leading designs.

- **Part 3: Keys to SMR Deployment and SMR Market Analysis**

**Chapter 10 – Keys to SMR Success for Suppliers** examines the steps that SMR developers will need to take to make their designs into commercial power plants.

**Chapter 11 – Keys to SMR Success for Customers** looks further into the factors for SMR deployment from the customer perspective. This chapter also includes a complete listing and analysis of the potential SMR customer base as currently known.

**Chapter 12 – Overall Analysis of SMR Market** provides broad analysis of the common themes arising from our SMR design assessments and considers the prospects for SMRs within the current nuclear power market paradigm. This chapter also provides summary analysis of the 12 leading SMR designs reviewed in this report and UxC's forecasts for each designs deployment in the future.

**Chapter 13 – Summary and Conclusions** reviews and summarizes the contents of this entire report.

In addition, a number of useful items to allow for comparative analysis of the 12 leading SMR designs are found in the accompanying **Appendices** as follows:

**Appendix A: Comparative Data for 12 Leading SMR Designs**

**Appendix B: Pros & Cons Comparisons for 12 Leading SMRs**

Finally, in order to help the reader decipher the large number of technical, regulatory, and nuclear industry terms used in this report, a lengthy **Glossary** is provided.