# SMR Deployment: FOAK (First-of-a-kind)

# risks & risk mitigation strategies

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**Abstract**

To realize the full potential of SMR technology towards a long-term, global future based on clean energy, the nuclear industry has to successfully surmount a number of key challenges. While the new generation of nuclear technology, in the form of numerous SMR options, holds tremendous promise, the successful commercialization of these new reactors has to address several critical elements. Chief among these is the development and construction of First-of-a-Kind (FOAK) projects. While any FOAK project, in the energy industry or otherwise, is challenging in its own right, nuclear FOAK projects carry a distinctive level of complexity due to a unique combination of technical, financial and regulatory burdens. Even in instances where specific SMR designs are based on sound technology, with promising results in laboratory environments, the process of converting this sound technology to successful commercial product is long and arduous. This paper will undertake a comprehensive assessment of the risks associated with SMR FOAK projects and propose plausible mitigation strategies for these risks.

## INTRODUCTION

As a long-tern option for clean energy, nuclear technology has tremendous potential to be a critical, and substantial, part of our zero-carbon future. In recognition of this fact, there is growing acceptance of nuclear technology as a part of our clean energy portfolio. A crowning achievement in this progression, was the acknowledgment at COP28 that nuclear energy could play a critical role in the mitigation of the effects of climate change [1].

To accomplish this large, strategic objective, however, nuclear energy has to evolve beyond its current technology, form factor and deployment model. While the nuclear reactors deployed to date, have mostly served us well, the underlying technologies entail significant complexity in design, deployment and operation. Additionally, the prevailing wisdom in the nuclear industry has been that economies of scale demand the deployment of nuclear technology in large form factors. As a result, traditional nuclear projects have been overly expensive with overly extended time period for completion. The resulting size and complexity of these large nuclear projects has precluded their deployment in the developing world, with a limited capacity to deal with the same; ironically, since this is also the part of the world that stands to gain the most from cost-effective, clean energy [2].

SMR are well positioned to address the current challenges associated with nuclear energy. In most cases, the Gen IV technology that forms the basis for the emerging systems, makes them significantly easier to design, deploy and operate safely. At the same time, the modular form factor of the systems obviates the need for a large, up-front investment, in favor of a build-as-you-need approach. Additionally, the design of these systems, based on standard, factory-built components results in economies of scale associated with manufacturing in volume, even as it redefines the entire construction process. No longer requiring major fabrication on-site, the significantly modest construction process now entails, for most part, simple assembly, at a fraction of time and cost.

The benefits of SMR highlighted above position them uniquely for a global deployment in the service of addressing the existential challenge of climate change. However, the potential, large, long-term deployment of SMR has to first navigate the hurdles faced by all new technologies in general, and nuclear energy in particular. Key among these is the daunting hurdle presented by the FOAK project. This paper will discuss the major risks associated with nuclear FOAK projects, and also offer key mitigation strategies for the same. Specifically, the list includes Technology Risk, Financial Risk, Regulatory Risk, Strategic Risk.

## technology risk

The most obvious risk for an SMR FOAK project is that related to the maturity and development of the underlying technology. Across the entire range of GEN IV options, different technologies might be at different Technology Readiness Levels (TRL) [3]. However, regardless of a relatively higher TRL for a particular technology option, the process of converting technology to commercial product is long and arduous. This is particularly true for nuclear energy, given the heightened concern related to safety, and the associated regulatory oversight. Compounding the challenge is the fact that a commercial nuclear energy system is an integrated implementation of a number of diverse technologies that, during the FOAK project, could be at differing TRL.

The technology risk for an SMR FOAK starts at the core. In most instances where the proposed reactor is based on GEN IV technology, the reactor is fueled by uranium at a higher level of enrichment, called High Assay Low Enriched Uranium (HALEU). A valid choice based on performance considerations, nonetheless, this choice presents two obvious risks. Firstly, the safety case of a nuclear core based on HALEU has to be successfully demonstrated, both in terms of neutronics and thermal hydraulics. Secondly, a commercial supply chain for HALUE has to be established, where none exists today. Given the magnitude of this effort, and the number of different companies involved, the aggregate risk could be significant. Even in instances where the underlying technology is an extension of current options, the notion of modularity could result in a disaggregation of the core in a manner that has not been done before. While presumably this is could simply be an incremental step from our current implementations, nonetheless, its safe technical viability has to be proven at scale for the first time.

Additionally, GEN IV SMR are proposing new methods of heat transfer, from the core to the energy conversion systems. In some instances, the heat transfer medium is metallic; in others, it is molten salt. Both valid choices for various reasons, nonetheless this is a significant departure from the norm. And a FOAK project presents the first commercial opportunity to demonstrate the effectiveness and safety of these options at scale. At the same time, the proposed use of energy conversion systems not traditionally used in the commercial nuclear industry (e.g., Brayton Cycle) is intriguing. However, this also adds to the technology risk profile. Lastly, one of the strongest propositions of SMR is that of passive and/or inherent safety. Though different in significant aspects, these two notions, regardless, are intended to offer a more effective safety profile for commercial nuclear operation. But, again, a FOAK project presents the initial opportunity for the effective demonstration of these concepts at scale.

Conceptually, it is important to recognize that even in instances of nuclear technology commercialization where significant laboratory experience exists, the transition of technology to commercial product is not linear. Scale brings its own complexity, particularly for nuclear energy. A commercial environment does not have the benefit of shelter that a laboratory enjoys, and the relatively high-capacity factor successfully established by the existing fleet is an expected standard that has to be achieved and maintained.

In recognizing the technology risks listed above, two additional facts have to be acknowledged. Firstly, some the identified risks have a significant macro component and, therefore, could be beyond the purview of a single company to address. HALEU supply chain is one such risk. However, this risk is being actively addressed by a number of like-minded governments, including the United States, through significant funding and attention. This paper does not intend to focus on such risks.

At the implementation level, there are technology risks that could be mitigated by the project. For such risks, the mitigation strategy proposed is one of simplification plus effective management of the product life cycle. The success of the proposed strategy starts with a recognition that a significant component of value that a FOAK project could deliver is its successful completion, reasonably on time, and reasonably close to budget. Ignoring the potential paradox in the statement and its inherent subjectivity of expectation, the message is simple. A nuclear FOAK project that drags on carries a significant cost, tangible and intangible, for all its stakeholders even it is eventually completed; and it has significant long-term implications for any transition to Nth-of-a-Kind (NOAK). Vogtle is an obvious example [4].

To improve the probability of success, it is critical to complete an early, simplified, technical definition of the project at the front end and stick to it throughout the project, except for changes related to the safety case of the nuclear system and to satisfy the regulator regarding the same. This notion of simplicity should carry through all technical aspects of the project, including the definition of the supply chain. In selecting suppliers, cost should not be the primary consideration. Rather, the selection should be made based on technical capability, stable and proven track record, optimal delivery logistics. While supplier diversity is a crucial objective in long-term product management, single-sourced component, or sub-system, acquisition is preferable as the FOAK project navigates a relatively steep learning curve.

 Relatedly, to effectively accomplish the above, this paper proposes the use of an empowered product management function that is quite common in the technology commercialization process in other industries, but surprising lacking in the nuclear industry. Distinct from project management, product management is a boundary spanning role that bridges the gap between design and development, project management and the customer. By definition, a product manager owns a product across its entire lifecycle; from inception to end. Of course, given the extended lifecycle of a nuclear reactor design, the scale of the product management process is different. Nonetheless, the basic principles of product management still apply, including the fundamental requirement of ensuring the delivery of the right product at the right time.

## financial risk

A second obvious risk for as SMR FOAK project is the financial risk. Given the sheer, inherent, complexity of any nuclear project, doing it for the first time presents the principals with a daunting learning curve. While the slope of the learning curve can be reduced through the effective management of the various risk components, a FOAK project will always carry a level of uncertainly that is unique. A direct impact of this uncertainty is on the associated financial model for the project, including the very availability of the required funding.

The financial risk associated with FOAK projects can be broken down into two broad categories. The first one relates to getting the project financed, appropriately, at the front end. The obvious potential sources of funding include governmental support, direct and indirect, and private financing. Given the relatively high risk profile of nuclear FOAK projects, the relationship, and balance, between these two options is crucial. It is understandable that private capital is naturally reluctant to participate in a FOAK project that, by default, has an uncertain cost structure and therefore a less well-defined financial return. This acknowledged risk for private investors could be mitigated by an appropriate level of government support, either in direct form as with the Advanced Reactor Demonstration Program (ARDP) in the United States or indirectly in the form of loan guarantees, subsidized loans, and tax incentives like Investment Tax Credit (ITC) and Production Tax Credit (PTC) [5, 6].

Besides the obvious infusion of much needed inexpensive capital into the FOAK project, the listed government assistance reduces the funding requirements of the private market and indicates strong national, or regional support for the project. In the absence of such a balanced financing package, the FOAK project risks being undermined from the start, with inadequate funding resulting in the obvious downstream risks of delay, incremental cost and lowered probability of success.

Even if the FOAK project starts with adequate funding, the second category of risk presented to the project is that of appropriate financial management, to minimize the inevitable cost overrun, and to ensure the availability of funding throughout the project. In this process, milestone based incremental funding could be expected. This could be true for both public and private financing. In such cases, the most effective mitigation of the risk of missed milestones, and the associated risk of missed funding tranches, has to be upstream. At the same time, a more liberal assessment of contingency at the front end of the project should reduce the risk of a funding squeeze during the project.

In ensuring the success of any nuclear FOAK project, the initial definition is crucial. Included in the definition is the financial expectation from the project. Given the significant, initial costs required to be borne by a FOAK project, it is challenging for such a project to be economically viable on its own. The obvious challenge is that of translating the relatively unattractive initial investment into long-term, competitive returns for the same investors. In this regard, single unit FOAK projects will be difficult to justify. Instead, a project definition that includes multi-pack deployment is more attractive. Of course, the notion of fleet deployment has received significant attention lately. While an attractive concept, its implementation across multiple markets, or even a single one, requires a complex business model spanning multiple entities and differing expectations.

While it is tempting, and seemingly logical, to apply the same financial approach to nuclear FOAK projects as to other projects, it is impractical and unrealistic to do so. Eventually, the expectation is that at NOAK, a nuclear project will be sufficiently competitive, economically, to justify its operation. However, without FOAK, there is no NOAK. And the transition from FOAK to NOAK can only be undertaken in the larger context of public policy based on broad public support. With such support, it is possible to present the relatively larger, and economically challenging, investment in a FOAK project, with a significant public component, as a national investment in support of strategic objectives.

## regulatory risk

A singular factor that differentiates nuclear projects from others is the intense, and sometimes arduous, regulatory oversight. Given the global sensitivity related to nuclear safety, this oversight is understandable. And, given that a FOAK project is the first commercial deployment of a nuclear reactor, expectedly, the oversight is at its peak for such a project. In fact, successfully navigating through this oversight is a key requirement for the timely completion of a FOAK project. Additionally, this effort requires a substantial, and unavoidable, investment in time, effort and money.

In response to the strong, emerging interest in nuclear energy, particularly new technologies and form factors, the nuclear regulatory bodies around the world have stepped up their efforts to appropriately update their procedures, operation and capability, and to acquire the new expertise needed for the effective oversight of a rapidly changing market landscape. While some agencies have made more progress than others, nonetheless, all of them face a significant learning curve in this transition. This in turn, poses an additional risk for FOAK projects as they are forced to deal with a changing regulatory regime, the definition of which has not been completed yet.

In this prevailing regulatory environment, it is advisable to engage with the regulator early. This engagement could be in the form of pre-licensing or pre-application discussions with the regulator, intended to comprehensively frame the upcoming, formal licensing engagement and to receive early feedback from the regulator to identify any potential showstoppers in the process. In certain regulatory environments, like Canada, there is a formal mechanism for such early engagement. Called the Vendor Design Review (VDR) process, this is an option available to all reactor developers interested in participating in a formal licensing application in Canada at some point in the future [7]. However, even in regulatory environments that do not offer the option for such a formal interaction, it is still possible, and encouraged, to engage with the regulator informally. In the United States, such pre-application engagement could include organized meetings with the NRC, submission of white papers for review, and any other regulatory guidance deemed appropriate by the developer well in advance of a formal licensing application [8].

While the early regulatory engagement described above could have significant value for the FOAK project, its full effectiveness depends upon how formally it is integrated into the technology and product development process. Such regulatory engagements are valuable if they make an immediate, and ongoing, impact, with the specific intent of derisking the FOAK project. In this regard, given the limited time and resources, careful prioritization and sequencing is essential. Additionally, with early regulatory engagement in environments less formally defined, further effectiveness, and optimization of resources, can be accomplished through a focused interaction with the regulator rather than a broad based one.

Lastly, a successful mitigation of the regulatory risk discussed in this white paper depends upon the human factor. Cliched as that might sound, given the complexity of the task, and its extended duration, organizational stability is a critical success factor. In this regard, a robust infrastructure of well-defined processes, and suitable information management technology, can help address the inevitable issue of personnel burnout. At the same time, it is important to have a balanced skill set on the regulatory team. While domain expertise is important, in the form of individuals well versed in the specific regulatory process in question, it is also essential to have a healthy mix of individuals with a broader range of experience. Particularly relevant is the ability to derive results in a highly fluid and uncertain operational environment.

## strategic risk

The last risk addressed in this white paper is the strategic risk. Often ignored due to its intangible nature, nonetheless, this risk could be the most crucial in FOAK projects, particularly nuclear. To a large extent, this risk highlights the need for strategic alignment between all the principals involved in the FOAK project, and the acceptance of a common definition for the same. A well-defined FOAK project should have clearly stated strategic objectives at the outset, and a strong commitment to such objectives by all stakeholders.

By default, it is challenging for a FOAK project to be economically viable. And yet, the path to a financial return needs to be clearly understood by all parties, long as it may be. In this regard, the strategic rationale for the FOAK project needs to be clearly articulated by the owner of the asset, either an owner-operator, or a Special Purpose Vehicle (SPV) established specifically to create the asset. Ideally, a single FOAK unit has to be the start of a larger business enterprise, either through the deployment of additional units at the same site, or the deployment of a fleet of reactors in a particular region; or nationally. It is crucial for this transition to be well defined in timing, expected economic outcome, potential risks, and the proposed mitigation. While a well-defined financial model at the front end of the project should help, this is not just a financial exercise. Given the inherent financial uncertainly in a nuclear FOAK project, any financial modelling at this point will be lacking. Enduring support from the major financial stakeholders, comprising the starting coalition for the project, has to be based on the potential long-term, and strategic, value enabled by the project; value extending beyond the immediate economics of the FOAK project itself.

Absent the comprehensive support discussed above, the starting coalition for the FOAK project might not endure for the duration of the project. While such churn is not impossible to manage, the resulting increase in the risk of the project will negatively impact its probability of success. For this reason, it is important to form the starting coalition carefully, with particular attention to the financial risk profile of the individual stakeholders, their long-term vision for the project, their strategic reasons for participation, and their financial durability. Relatedly, for SMR developers leading this effort initially, the desire for an early customer has to tempered by the recognition that not every customer is suitable for a FOAK project.

Expanding beyond the direct stakeholders, the FOAK project should have strong support within the expanded community of customers, local governmental organizations, and advocacy groups. This support is particularly crucial as, inevitably, the project goes through expected and unexpected challenges. To ensure such support on an enduring basis, a proactive outreach program is essential. Starting with a clear definition of all expanded stakeholders, and their specific requirements, the program should proactively engage with the same with an intent of inclusion. This, in turn, should result in a sense of community ownership that often sustains a FOAK project through times of adversity.

## conclusion

The rapidly growing global interest in nuclear energy is based on the recognition that the desired zero-carbon environment of the future is not possible without a significant inclusion of nuclear in our long-term energy portfolio. To realize the full potential of nuclear energy, in this regard, the key challenge is to enable a timely expansion of the global nuclear footprint. SMR offer particular promise in the pursuit of this objective. However, given the early nature of the associated technologies, and the resulting products, a critical hurdle in this effort is the transition from FOAK to NOAK.

While, by default, FOAK projects are always difficult, SMR FOAK projects have unique challenges. The relative complexity of extended technology development, in concert with regulatory oversight, and the establishment of a global supply chain, often including single-sourced components, can present such projects with a formidable risk profile related to cost and timing. This often results in an economic model that is biased against the profitability of single unit deployments. This implies that even as SMR could offer the advantages of modularity, including the simpler logistics of design, deployment and operation, a comprehensive risk assessment is crucial for the success of the project.

This paper has attempted to provide an effective framework for such a risk assessment. Given the nature of this publication, the accorded treatment is in favor of broad coverage. It is hoped that by the end, this paper provides the reader with a comprehensive understanding of what the risk profile of an SMR FOAK project could look like. Additionally, the paper is intended to propose some plausible risk mitigation options that have drawn from the experience of other industries. This discussion has tried to cover both tangible and intangible risks. The distinction between the two is an important consideration. Specifically, while the financial risk is tangible, and therefore relatively easier to address, strategic risk is often the most critical. Unaddressed strategic risk will have downstream impact on the project that will increase its risk profile and could even jeopardize it entirely.

Collectively, the nuclear industry is learning from its nascent SMR experience. In this regard, every successful FOAK project improves the credibility of our industry and adds to its cumulative ability for SMR deployment; every disappointment has the opposite effect. While there is no single factor that could completely address the unique risks of an SMR FOAK project, a comprehensive, pragmatic and continuing risk assessment throughout the project life-cycle should help.

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