Program on Technology Innovation: Advanced Reactor Cost Model Guide Development

Scoping Study Summary Report

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All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

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ABSTRACT

This document summarizes the results of a scoping study to understand the feasibility and need for a standardized approach to model costs for advanced reactors (ARs). EPRI hosted a stakeholder workshop, to gather information on needs and to discuss the main issues, benefits, and challenges related to development of a standardized cost modeling guide (CMG). These stakeholders included AR developers and vendors; potential owner-operators such as utilities; engineering, procurement, and construction (EPC) firms; and research and development (R&D) organizations.

The main conclusion is that a standard AR CMG would be a useful resource to support ongoing and future planning for AR commercialization. Specifically, the key approach identified for developing a practical and value-laden CMG will be the integration of standardized language in the development of a standard generic cost breakdown structure (CBS) that parallels traditional work breakdown structures (WBS). The EPRI CMG for ARs is intended to proceduralize cost determination in a consistent manner to inform decision-making.

A standard AR CMG will have value if it goes beyond a software template by providing guidance on what should be included in a cost estimate and how it should be assessed. A process needs to be defined to ensure a common understanding of the requirements. It should be a framework akin to the Owner-Operator Requirement Guide (ORG) that informs buildup of costs using a standardized hierarchical breakdown of the project and common (standardized) language. Ideally, estimates prepared by different people for the same plant or different plants will have sufficient commonality in approach such that lack of agreement on values will be the result of varying opinions or sources of data, not the result of inconsistencies in treatment. The CMG could be used as an input to expand and improve the industry dictionary, as a first step to develop a standard language surrounding nuclear energy.

Keywords
Advanced Reactors
Cost modeling
Work breakdown structure
Plant lifecycle
Standard language

ACRONYMS/DEFINITIONS

AE	Architect Engineering
AR	Advanced Reactor: these include water-cooled small modular reactors (SMRs), non-water-cooled reactors, and the various microreactor concepts.
BOP	Balance of Plant
Bulk commodities	Products that are relatively inexpensive.
Capital costs	Up-front expenditures related to plant construction.
Change orders	Work that is added to or deleted from the original scope of work of a contract, however, depending on the magnitude of the change, it may or may not alter the original contract amount and/or completion date.
Commodity prices	The price of a commodity based upon the market in which the commodity is located and needed.
Commodity	A tangible good that can be bought and sold or exchanged for products of similar value.
Cost estimate	The approximation of the cost of a program, project, or operation.
Cost impact metric	A defined system or standard of measurement to track the costs of change in project.
Cost model	Simple equations, formulas, or functions that are used to measure, quantify, and estimate the effort, time, and economic consequences of implementing a project.
Davis-Bacon	Davis-Bacon Act and Related Act contractors and subcontractors must pay their laborers and mechanics employed under the contract no less than the locally prevailing wages and fringe benefits for corresponding work on similar projects in the area. The Davis-Bacon Act directs the US Department of Labor to determine such locally prevailing wage rates.
Design engineering	An in-depth investigation and draft completed prior to the construction of a new project.
Digital engineering	The practice of creating, capturing, and integrating data using a digital skillset. This can include simulation and 3D modeling.
Direct Costs	A price that can be directly tied to the production of specific goods or services.

Estimate Class Level	Based upon guidelines and general estimate principles, an estimate can be broken down into levels of probability that a project will successfully meet the estimated cost.
FOAK	First-of-a-Kind
FOB	Freight on Board
FPO	Flexible Power Operations
Full cost recovery	Securing funding for all the costs spent on running a project.
HALEU	High-assay low-enriched uranium
Import/export fees	Import or export duties or taxes, and all other charges related to port or customs clearances, including pilotage, agent fees, brokerage fees, handling charges and port dues
Indirect costs	Costs that are not directly accountable to a cost object. Indirect costs may be either fixed or variable and are usually costs that are not directly related to production.
Inflation	General increase in prices and fall in the purchasing value of money.
INPO	Institute of Nuclear Power Operations
ITAAC	Inspections, Tests, Analyses, and Acceptance Criteria
ITP	Initial Test Program
Management reserve	The amount of contract budget set aside for management control purposes rather than designated for the accomplishment of one or more tasks. This is accounted for in capital costs.
Material cost	The costs of materials used to manufacture a product or provide a service.
Modularization	The design or production of something in separate sections.
MSR	Molten Salt Reactor
Maturity	The agreed-upon date on which the investment ends, often triggering the repayment of a loan or bond, the payment of a commodity or cash payment, or some other payment or settlement term.
NEI	Nuclear Energy Institute
NOAK	Nth-of-a-Kind
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
O&M	Operation and Maintenance

ODCM	Offsite dose calculation manual
OEM	Original Equipment Manufacturer
Overhead costs	The ongoing expenses associated with operating a business. For an AR project these can include, fuel cost, staffing etc.
Overnight costs	The cost of a construction project if no interact was incurring during the construction time.
Profit margin	The ratio of a company's profit (sales minus all expenses) divided by its revenue.
Project contingency	The estimate associated with the unknown costs in a project.
QA	Quality Assurance
Sale Price	The price paid by the buyer at the time something is sold.
Segregation of costs	The separation of costs based upon a previously agreed upon contract.
SMRs	Small Modular Reactors
SSCs	System, Structure, and Components
Stakeholder	A party that has an interest in a project/company and can either affect or be affected by the business.
Standardization	The process of implementing and developing technical standards based on the consensus of different parties that include firms, users, interest groups, standards organizations, and governments.
Stick build	Building of component on site.
Stockpile	A large accumulation of goods or materials
Supply chain	A system of organizations, people, activities, information, and resources involved in supplying a product or service to the project.
Turnkey EPC	Engineering, Procurement, and Construction, with turnkey assuming complete service to the client and delivery of the project ready for operation.
Underbid	The submission of a lower than achievable project estimate in the hope of securing the work on a project.
WBS	Work breakdown structure

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1 INTRODUCTION

Purpose

Advanced Reactor (AR) designs typically offer features and attributes that depart from those of light water reactors (LWRs) in terms of fuel forms, coolants, structural materials, size, safety margins, deployment model, and other important design and operational aspects. These departures relative to the industry experience will likely present a challenge for potential owner-operators when evaluating one or more AR designs for commercial deployment. Developing accurate cost and schedule estimates for new nuclear plant construction has proven challenging in many regions around the world. Cost modeling has been repeatedly identified as a priority R&D gap in previous EPRI AR workshops [1] and addressed in a recent EPRI report [2]. One important barrier to evaluating different technology options – or even understanding costs across a fleet of the same reactor design - appears to be a lack of consistency in terminology and breakdown of costs. Consequently, EPRI is considering the creation of a standard Cost Modelling Guide (CMG) for ARs to provide guidance and/or a set of tools to support the cost evaluation of diverse AR technologies on a like-for-like basis. The technologies EPRI considers to be advanced reactors include water-cooled small modular reactors (SMRs), non-water-cooled reactors (such as high-temperature gas-cooled reactors or molten salt reactors), and various microreactor concepts.

This document summarizes the results of a scoping study to understand the feasibility and need of a standardized approach to model costs for advanced reactors. As a key input for the study, EPRI hosted a stakeholder workshop, to gather information on needs and discuss the main issues, benefits, and challenges related to development of a standardized CMG. These stakeholders included AR developers and vendors; potential owner-operators such as utilities; engineering, procurement, and construction (EPC) firms; and research and development (R&D) organizations.

Background

Construction costs and project-scheduling models have been used in the power industry since the 1960s. Organizations frequently maintain their own cost models customized for their fleet or business to support decision-making based on key investment characteristics such as the type of plant, size, timing, and location. While the greatest magnitudes of cost estimate uncertainty exist early in the project, a degree of uncertainty persists despite estimate revisions. A clearer understanding of who owns specific costs and risks, and how to consistently evaluate them is essential for reducing cost estimate uncertainties. Without a standardized approach, iterative cost estimation is likely to be inefficient and may obscure drivers and sources of cost changes.

Risks associated with new nuclear projects could be mitigated through the use of a standard CMG developed specifically to compare, on a like-for-like basis, different technologies. A standardized CMG could enable the diverse range of AR technologies and designs to support future owner-operators, governments, and construction/engineering firms in the development of consistent and credible cost estimates to inform investment and procurement decisions and R&D prioritization.

EPRI has been actively performing R&D in the techno-economic assessment of nuclear energy and harmonization of design requirements. The following EPRI products can be referred to for more background reading and context:

- *Advanced Nuclear Technology: Economic-Based Research and Development Roadmap for Nuclear Power Plant Construction*. EPRI, Palo Alto, CA: 2019. 3002015935. – This report reviewed approximately 20 cost models and analyzed 11 of them for a more thorough evaluation.
- *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Revision 13*. EPRI, Palo Alto, CA: 2014. 3002003129. – This document contains technical and project functional requirements for advanced light water reactors.
- *Program on Technology Innovation: Owner-Operator Requirements Guide (ORG) for Advanced Reactors, Revision 0*. EPRI. Palo Alto, CA: 2018. 3002011802. – This document provides a guide for the development of ARs.
- *Program on Technology Innovation: Expanding the Concept of Flexibility for Advanced Reactors: Refined Criteria, a Proposed Technology Readiness Scale, and Time-Dependent Technical Information Availability*. EPRI, Palo Alto, CA: 2017. 3002010479. – This report provides additional understanding of AR flexibility attributes for ARs.
- *U.S. Regional Economy, GHG, and Energy (US-REGEN) Model Documentation*. EPRI. Palo Alto, CA: 2020. 3002016601. – US-REGEN is a detailed capacity planning and dispatch model of the electric sector that simultaneously determines investment and operational decisions. The model is solved as an intertemporal optimization through 2050 with five-year time steps with the intention of simulating a competitive equilibrium under alternative scenarios.
- *Exploring the Role of Advanced Nuclear in Future Energy Markets: Economic Drivers, Barriers, and Impacts in the United States*. EPRI, Palo Alto, CA: 2018. 3002011803. – This report investigates the conditions under which nuclear power could play a role in future markets. This study uses EPRI's US-REGEN model to explore tradeoffs across assumptions about technologies, markets, and policies.
- *Natural Language Processing and Its Application in the Utility Industry*. EPRI, Palo Alto, CA: 2019. 3002017321. – This document explores the potential benefits and challenges of the Natural Language Processing (NLP) in the nuclear industry.
- *Power Industry Dictionary for Text-Mining and Natural Language Processing Application: A Proof of Concept*. EPRI, Palo Alto, CA: 2020. 3002019609. – This document discusses the advantages of an industry-specific dictionary to conduct text mining and NLP-based algorithms.

As shown in Figure 1-1, EPRI's portfolio of products is intended and expected to complement and integrate with a standard CMG.

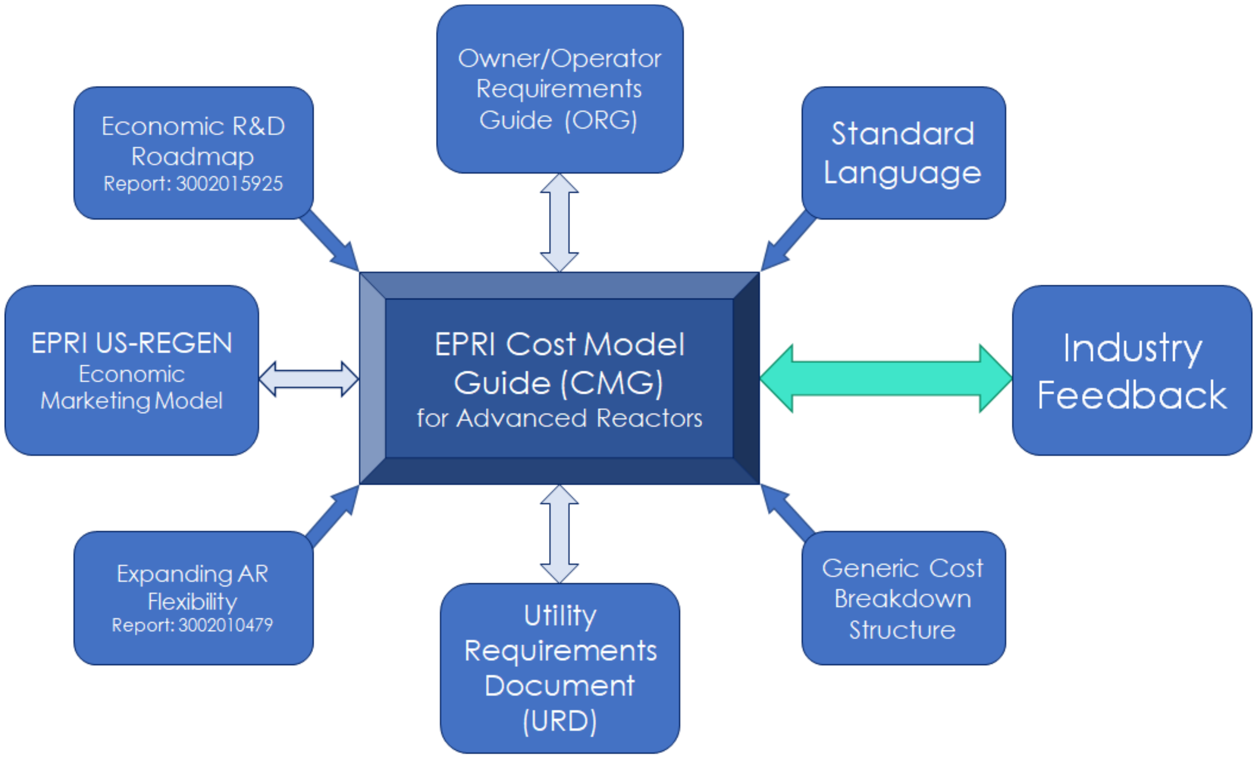

Figure 1-1
The interaction of the proposed Cost Model Guide (CMG) and the many EPRI products that inform, and can draw from it.

Approach

The goal of this scoping study was to assess the impact that a standardized cost model would have on each segment of the industry, and understand the elements that would make it successful. To do this, the following steps were taken:

- Literature review: Existing cost models, like the G4ECONS model maintained by the Generation IV International Forum (GIF) or the Energy Economic Database (EEDB) were reviewed and studied for their applicability to diverse advanced reactor technologies and potential deployment models.
- Identification of challenges: Issues and challenges related to successful development and implementation of a standard cost model were compiled into a matrix. This matrix of issues and challenges was categorized according to the life cycle of a nuclear power plant.
- Feedback solication: The draft matrix was provided to all interested stakeholders for collection of feedback prior to the workshop.
- Workshop discussion: With the matrix as the centerpoint of the workshop, time was spent discussing each of the individual lifecyle phases, as well as topics that encompass the entire life.

The workshop featured 45 attendees representing the following entities: Bechtel, Concrete Technology, Dominion Engineering, Duke Energy, EPRI, Exelon, General Atomics, Hitachi, LucidCatalyst, Massachusetts Institute of Technology, MPR Associates, Nuclear Energy

Institute, Nuscale Power, Organization for Economic Co-operation and Development-Nuclear Energy Agency (OECD-NEA), Ontario Power Generation, Rolls-Royce, Southern Company, Studsvik, Tractebel Engie, Tennessee Valley Authority, and Westinghouse.

Overview

This report is organized into the following sections:

- Section 2 – Provides key conclusions and near term actions
- Section 3 – Summarizes the topics discussed during the workshop
- Section 4 – Lays out the path forward and the proposed development approach
- Section 5 – Lists references
- Appendix A – Matrix of Issues and Challenges

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SUMMARY OF KEY CONCLUSIONS

The main conclusion of this scoping study is that a standard AR CMG would be a useful resource supporting ongoing and future planning for AR commercialization. Specifically, the key approach identified for developing a practical and value-laden CMG will be the integration of standardized language in the development of a standard generic cost breakdown structure (CBS) that works in concert with a work breakdown structures (WBS). The level of detail present in a WBS often exceeds what is needed by resource planners, developers, and end-users for their application of a cost model. However, architect/engineering (AE) firms or engineering, procurement, and construction (EPC) firms would need to understand how the WBS and granularity they require pair to a standard CBS used to inform the CMG. The EPRI CMG for ARs is intended to proceduralize cost determination in a consistent manner to inform decision-making.

The CMG could also incorporate a database to collect lessons learned on a shared platform. This can be used to update the CMG in a continuous process of improvement to the estimating basis. All of the aforementioned is designed to better support and improve the stakeholder's decision-making process and drive to successful project completion. A more detailed path forward is discussed in Section 4.

3 STANDARDIZED COSTING APPROACH ISSUES AND CHALLENGES

This chapter discusses the challenges and issues identified before and during the workshop to develop a standardized advanced reactor cost guide. The following assumptions were established to frame the discussion in the most inclusive way possible:

- The CMG should be technology neutral
- The approach should be country-agnostic
- The deployment model should not assume land-based deployment

The challenges were grouped into six different categories related to plant lifecycle: planning, pre-construction, construction, commissioning, operation, and decommissioning. In addition to these categories, some challenges were found to be general and related to all the phases of an AR life cycle. Two of the most important challenges identified were the need for a generic Cost Breakdown Structure (CBS) and the use of a standard language.

While a standardized WBS would be desirable for some, a standardized Cost Breakdown Structure (CBS) of less granularity might prove a more functional tool for many of the intended CMG users. [SJ1]The use of a cost model guide should encourage collaboration between the project participants and stakeholders, such as designers, operators, and construction personnel. Centering the CMG around a CBS could allow each of these stakeholders to benefit from the higher level conversations that arise, while reserving the granular details to internal WBS discussions. This is especially notable if the developed CBS is easily translated to each organization-specific WBS.

The absence of common language is a major challenge throughout the nuclear industry. Currently, naming of structures, systems, and components (SSCs) in the industry is highly variable and often specific to one plant. The absence of common terminology challenges standardization, like-for-like comparison, and objective assessment of the pros and cons of different technologies. An opportunity to improve this presents itself with ARs. The absence of legacy structure creates space to implement common language in the near term. New technologies, such as Artificial Intelligence (AI) employing Natural Language Processing (NLP), can accelerate the process and help homogenize naming conventions to form a common database. Currently, NLP development faces some challenges in the nuclear industry due to the lack of industry-specific vocabulary for training models and training data [9]. A common language database would simplify data transfer and comparison during operation, as well as in a standardized CMG.

Other intangible factors, such as inadequate reporting of design status or the maturity of the technology can affect the ability to develop a reliable CMG. An overly pessimistic view would price a design out of the market, whereas an overly optimistic one would underestimate the cost of a design. A standardized CMG should include an estimation of the confidence level for each design or project; the estimated confidence is elusive and often subject to excessive optimism at the beginning of the project when initial estimates are made.

The omission of costs that are less discrete than an individual SSC, such as those commonly grouped into "indirect costs" consitutes one form of optimism. Indirect costs are difficult to predict and an over-optimistic approach might be tempted to leave them out (additional discussion on indirect costs is provided in the next sections). This would be relatively easy to correct for the CMG, as it could enforce cost categories that include indirect costs explicitly.

Other forms of optimism might be more difficult to account for, such as the use of outdated cost data resulting from an absence of actual quotations, or the oversimplification of regulatory compliance leading to underestimation of regulatory costs. The CMG should be capable of quantifying the impact of broad assumptions and lack of information to avoid cost underestimation. Ultimately, this underestimation could be addressed in future versions of the CMG through the employment of accuracy calculations, acceptance of ranges as inputs, and the adoption of a standard for the level of accuracy and confidence. Incorporation of risk will help determine appropriate contingency and management reserve based on the level of input accuracy or confidence.

The maturity of the technology should be accounted for in the CMG using standard Technical Readiness Level (TRL) values, experience, history, and test data.

It is expected that AR projects will incur larger costs for the first several projects of a new design, commonly referred to as the First-of-a- Kind (FOAK) series[1]. The CMG should consider additional work and costs for these initial projects, such as R&D, equipment development, prototyping, equipment and process qualification, new codes and standards, new regulations, or lack of operating experience. This could be captured in the CMG through specific cost accounts and risk factors unique to FOAK, specifying what is attributed to FOAK and what expectations are for matured projects, the n^{th}-of-a-Kind (NOAK).

Finally, some factors might be difficult to capture today due to their rapid evolution. It is expected that ARs will employ advanced information technology systems such as cybersecurity, asset management, digital twin (DT), and configuration management. These systems will create an apparent increase in digital services but may in fact lead to savings through the life of the plant. The codification of DTs for ARs will require a significant amount of data and requisite networking infrastructure investment, and it is uncertain when the many individual technologies required will be capable of supporting such a system. Despite timeline uncertainties, DTs have the potential to reduce the cost of all the phases of a project's lifecycle, from design to operation and through decommissioning.

The following sections describe the discussion conducted during the stakeholder workshop and the challenges identified for each category.

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[1] The FOAK series of projects is not a clearly defined number and is based on such factors as when issues are considered to be reasonably fleshed out, supply chain is well established, and construction experience and best practices are mature.

Planning

The planning phase is a key step to define the strategy for implementing the five subsequent phases of the project. Site selection and characterization are determined during the planning phase, as well as roles and responsibilities of different organizations. To date, many roles and responsibilities of various parties, such as one firm to handle the engineering, procurement, and construction (EPC) have been assumed by default. While several other approaches could be adopted for the construction model, it is not the role of the CMG to assume any particular approach to construction, procurement, commissioning, operation, or decommissioning of future nuclear projects; the CMG must be agnostic and support any combination of options. To illustrate this point, a representative list of roles and responsibilities of parties in three potential approaches are summarized below:

- The original equipment manufacturer (OEM) could lead the project team, including the construction contractor, to deliver a complete, working plant. This could be most applicable for microreactor designs where the OEMs potentially minimal experience with construction and resource procurement may not be a significant challenge.
- The Owner acts as general contractor, managing the OEM, procurement, construction, and operations staff.
- The Owner places an EPC contract with a construction company, which is responsible for the entire build process through handover. The reactor design OEM would work directly with the EPC to provide the nuclear steam supply system (NSSS) design, components, and procedures.

Regardless of the project responsbilities outlined in this phase, the process and phase of planning is an Owner's responsibility. The level of planning and the assumptions considered should be captured in the CMG.

Pre-construction

Pre-construction is the phase during which many of the decisions that will define costs are made. Some ARs will be designed for missions beyond that of baseload electricity generation, and not necessarily the same as other instances of the same design. They may require mission specific SSCs to support cogeneration to produce process heat, output to an energy storage system, or produce hydrogen. The basic cost model process should be the same, regardless of application, but missions like cogeneration could change the approach to estimating the revenue required to build and operate the plant over a specified cost recovery period on a levelized basis[2]. Entering the industrial heat market would favor construction near or on an industrial customer's site. The CMG should provide guidance to the user on the financial impacts of existing infrastructure on construction.

Contracting strategy must be considered in estimating costs and associated risks. Multiple contracting strategies are possible: turnkey fixed price, cost-plus, cost-plus incentive fee, etc. Knowing what is not included is essential to both evaluating risk and ensuring the cost estimate is complete. Interaction among all stakeholders during the planning or pre-construction phase

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[2] Levelized Cost of Electricity (LCOE) vs Levelized Cost of Heat or Levelized Cost of Hydrogen, etc.

allows balancing of sometimes opposing perspectives to reach a consensus on approach and strategy to help define costs more precisely and potentially drive costs down.

Pre-construction costs can be summarized with the Sale Price, which is established by the vendors for the scope of the deliverable. The granularity of the Sale Price deliverable (which generally includes design engineering, NSSS cost, material cost, delivery, certain regulatory [a Design Certification or equivalent], possibly turnkey installation, and profit margin) influences the ability to predict final costs, including the appropriate risk factor and quantifying the costs that are not included in the Sale Price.

The licensing approach defined in the planning and pre-construction phases also influences the Sale Price and project timing. Although there is a trend in harmonizing licensing (such as between the US NRC and the Candian Nuclear Safety Commission [CNSC]), licensing approaches are currently dependent on the geographical area and country.

For ARs, two major licensing strategies are expected to be used. The first is to build what you license, which in the US is done through Title 10 of the Code of Federal Regulations, Part 52 (10 CFR 52) in the existing LWR regulations. With this method, the designer develops a design certification, and bears the costs of getting approval from the regulator for a safety-related NSSS system. If deviations from the certified design are needed during construction, a license amendment is required. The second approach is to license what you build, in the US this would be done through 10 CFR 50. When using the "license what you build" approach, the owner bears licensing costs, and deviation from the original design can be made during the construction phase without the need for amendments. The former approach places a premium on early design maturity, which affects several contributors to regulatory costs, such as payment for regulator reviewer hours, applicant time to prepare applications and support analyses and respond to regulator questions.

In general, the CMG should accommodate various regulatory frameworks to inform the user independent of the licensing approach and geographical area, such as shown in Figure 3-1. Independently from the design approach that will be implemented, a cost model should inform on the different outcomes between the two approaches. In addition, the CMG should incentivize a constant dialogue between the designers and other stakeholders (constructors, operators, supply chain, modularization experts, etc.). Such a dialogue between stakeholders should help reach a design that can be successfully constructed and discourage construction before the design is completed.

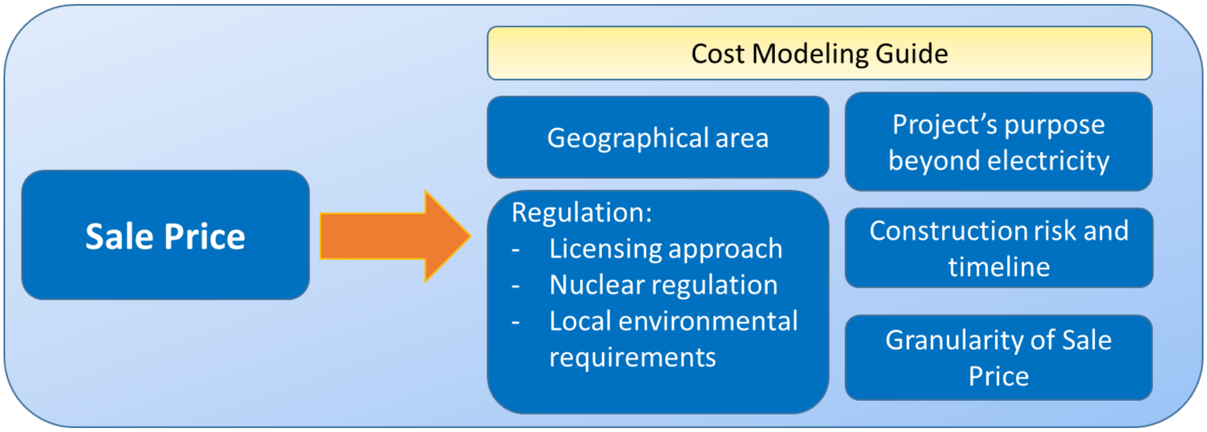

Figure 3-1
Cost Modeling Guide Approach to Pre-Construction

Construction

Construction costs are primarily capitalized costs, commonly divided into direct and indirect costs, further detail of which is shown in Figure 3-2. Both of these categories have a lower limit involving continuing costs to keep the project running, even if little or no actual progress is being made. In addition, financing costs need to be considered.

Costs related to the construction phase are dependent on the duration of construction, which affects the cost of financing and, in case of delays, adds costs in the form of inflation and financing charges. Depending on the contracting strategy, the granularity of costs and access to underlying bases will vary. Knowing what is in a cost category, and perhaps more importantly what is not, may be difficult. The initial allocation of construction cost is based on the scope of deliverables included in the NSSS vendor's Sale Price and may require making assumptions on how to allocate contractor cost estimates in relation to the cost model. The subsequent binning of construction costs not included in the NSSS vendor's Sale Price is driven by the Owner's construction strategy, project contingency, and management reserve. Some AR designs are expected to produce not only electricity, but also heat and/or hydrogen. This multi-purpose approach will be supported by cogeneration or alternate energy production equipment that might add to capital cost depending on the plant capabilities. This additional capital cost might need to be balanced with the sources of revenue beyond electricity and the ability to rebalance output to enhance revenue.

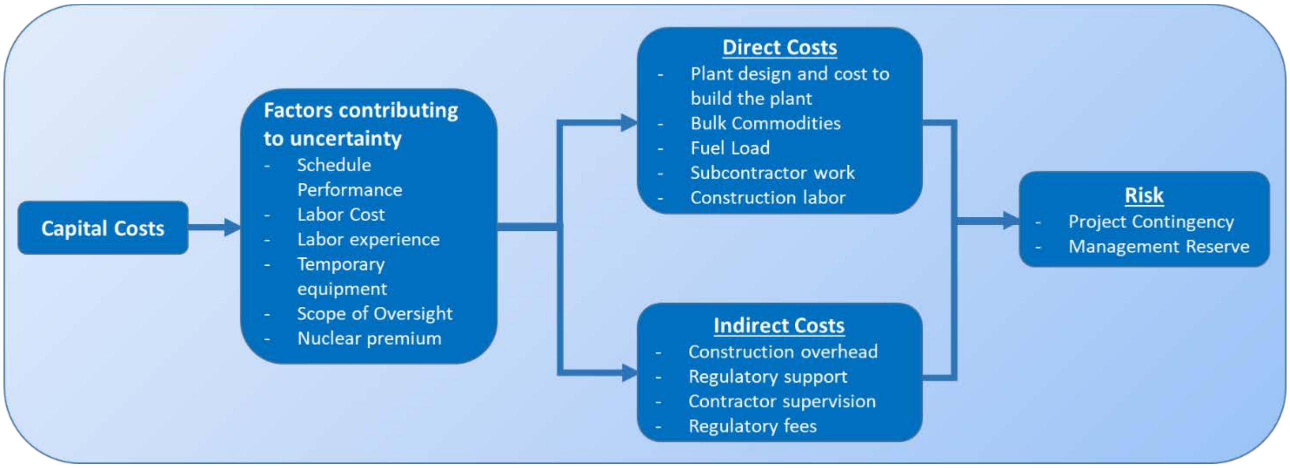

Figure 3-2
Capital Costs Distribution

Several representative assumptions that can cause fluctuation in the construction cost include:

- If the Owner's costs (land, site work, project management, administration, startup costs, taxes, and insurance) are included in the estimate
- The basis used to calculate project management reserve
- The basis used to calculate project contingency[3]
- The ability to capture other items that constitute capital costs, such as direct and indirect costs, are discussed below

Direct costs are comprised of several different activities, each with its own characteristic spend curve and sources of uncertainty. Depending on the structure of the contract, different entities will bear the risk for each activity. Some of these activities are:

- Plant design, which represents what the costs are to build the plant
- Long lead components , bulk commodities, and initial fuel load
- Subcontracted work and construction labor, which must consider changing labor market conditions during the project, variation by location, need for incentives for key trades, local and national competition for workers, union or non-union workforces dependent on location, on-boarding costs for new workers, and external constraints

Indirect costs include the capital required for construction overhead activities and other costs not included in the direct costs such as project management, contractor supervision, some regulatory charges (namely direct licensing charges such as regulator labor), and licensing support (analysis and document preparation, legal support). Indirect costs are often underestimated due to the lack of consistency surrounding their communication. Efforts to cut budgets frequently start with indirect costs because they can represent "overhead," but elimination of indirect activities can

[3] Project contingency is related to the uncertainty of the project, which will trend high for several of the first AR builds due the significant departure of ARs from previous technologies, and thus low levels of experience and the subsequent lack of data.

often lead to larger increases in actual direct costs as a result of inefficiencies. [MD2][MD3]An example of this is how reduced warehouse staff can slow construction work as a result of delays in providing material. Sometimes these indirect costs are not even included in a cost estimate because they are viewed as minor or because of the difficulties to quantify them precisely.

The CMG should take into account that cost projections are often prone to under-estimation because of incomplete identification of costs and over-optimistic views on efficiency. There is also a natural tendency to select models and values that do not unduly penalize a project. The CMG should help the user reach a realistic estimate and help reviewers assess the level of conservatism.

These considerations on construction could be addressed in the CMG using uncertainties, sensitivities, and risk management. In order to make an accurate cost estimate, all factors contributing to uncertainty should be considered, including the following:

- Application of new technologies with which stakeholders have limited experience leading to unexpected problems, possible changes during construction, and regulatory delays
- Schedule performance impacts due to unexpected site conditions and weather-related delays, missing items, and procurement delays
- "Nuclear premium" which could be underestimated
- Cost of temporary storage (such as storing material that arrives on time but construction is behind schedule) and lay down
- Inaccurate quantity estimation for bulk commodities, replacement of components damaged during transport (either under- or over-estimating needs leads to higher cost)
- Labor cost, which includes underestimation of crafts hours, low worker productivity, and need for incentives for craft labor (e.g., per diem, key trade premium)
- Temporary equipment (such as crane rentals)
- Oversight of work and disputes among project organizations

Uncertainties are often affected by new approaches to construction, schedule, and costs that could rely on standardization and modularization. The risks and factors affecting costs associated with modularization are less understood than those of traditional construction. The extent of modularization can vary greatly, from a limited number of subsystems to the entire nuclear heat source. Use of off-site modular construction techniques as opposed to conventional practices have potential financial advantages such as improved quality; reduced rework; reduction of hiring, training, and relocation costs; and less vulnerability to work stoppages on-site. They also can have less obvious costs related to correction of problems not recognized until after arrival at the site, or requiring more expensive site equipment (such as cranes). Another form of risk arises from potential delays in delivery of major modular sections, causing delays in critical path task completions and impacting the overall construction schedule.

Modularization and standardization are expected to reduce the need for site-specific engineering, and the quantity and scope of change orders. This change in philosophy is not without risk. Employing external fabrication facilities introduces economic risks related to the rate of order receipt required to maintain the facilities' ability to maintain operation. Their use could expose the plant to supply chain delays, reducing the workaround options. Moreover, both standardization and modularization may require new fabrication facilities that depend upon large capital investments, and it is not clear who will bear these costs.

Commissioning

Commissioning starts near the end of a plant's construction. During this phase, the systems and components are made operational and verified to be in accordance with design and regulatory requirements. Also referred to as the Initial Test Program, activities occur in three steps: pre-commissioning, commissioning, and startup. Pre-commissioning activities are conducted by the construction contractor and, as required, major equipment vendors. They involve various inspections, acceptance testing of components and certain systems, and instrument loop checks. The responsibility for correcting discrepancies still lies with the construction contractor but would include the owner's operating staff and certain vendors. Pre-commissioning progressively transfers sub-systems, systems, and plant areas to the commissioning group. Once turned over to plant operations, activities must be performed by the licensed operators following formal procedures developed by or with assistance from various OEMs.

During commissioning the plant is almost ready for operation. Authorization to operate depends on the results of testing, but the systems are new and operators may be new to using them. Deviations can have regulatory implications. While it is recognized that FOAK designs will involve more tests and require more time to resolve discrepancies than subsequent projects of the same design, the need to allow margin for first for our team (FFOT) commissioning is not always considered.

Many factors influence the approach used during the commissioning phase. Figure 3-3 provides a high-level graphic of factors that affect commissioning costs such as:

- Licensing choice: for example, in the US the use of a Part 52 approach would require completion of inspections, tests, analyses, and acceptance criteria (ITAAC) during the commissioning phase in order to obtain authorization to load fuel.
- Scope of construction: constructor's and/or OEM's costs versus owner's costs; the two former costs would be included in the contract prices, respectively.
- Spare parts procurement and management: the contractor should provide all commissioning and start-up spare parts.

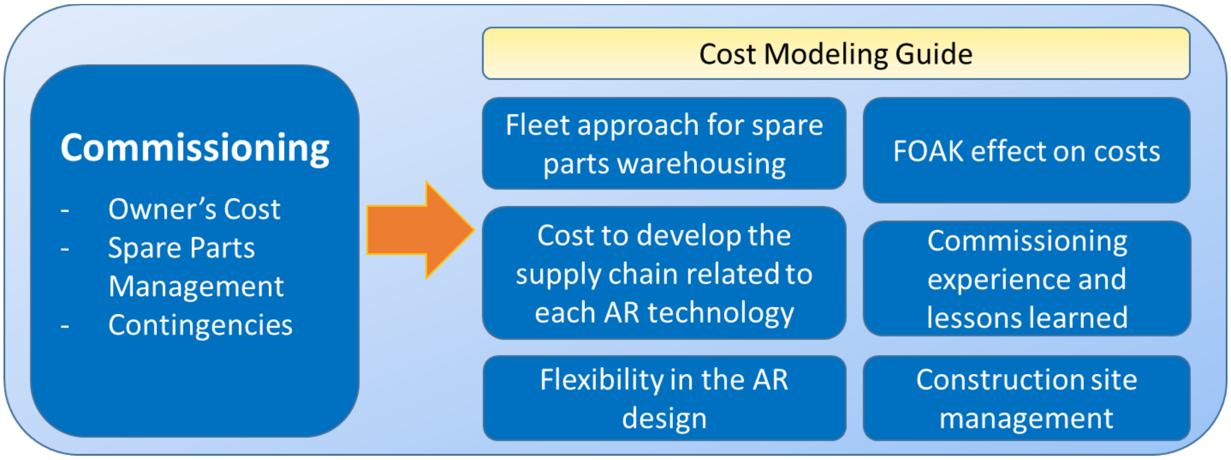

Figure 3-3
Cost Modeling Guide Approach to Commissioning

Spare parts management strategy is expected to change significantly for ARs. It is likely that a fleet approach for spare parts warehousing will be considered, where the owner/operator (or consortium of owner/operators) maintains one or more warehouses stocked with theses spares to lower costs. This approach can help negotiate more favorable commercial terms (such as only paying for parts used with a "member" fee), and reducing the cost of maintaining a significant spares warehouse on site. However, one disadvantage of a fleet approach like this is related to the initial investment required to develop a common pool of spare parts.

As a transition period to owner/operator control, the success of commissioning relies on comprehensive construction site management. Turning over systems on time is necessary to avoid cascading delays and loss of worker efficiency. To achieve this goal and minimize risks and costs, workflow planning and project controls must be mature. The construction site should be organized to sequence work, minimize downtime, and allow optimal integration among the different systems to transition to operation smoothly and on time.

Contingency and management reserve funding is expected to be high for the commissioning phase for the first several plants of a particular design and for the first instance of new build for the owner/operator. For example, regulatory requirements and the regulatory body acceptance of commitments will change with the number of plants of the same design constructed and in operation. The scope and cost of the Initial Test Program will decrease as subsequent plants are brought online. In order to mitigate the contingency and management reserve funding costs from unexpected commissioning issues, flexibility should be built into planning to meet regulatory requirements.

The CMG should help estimate the commissioning costs, such as:

- Capturing information on the costs for all estimated additional equipment and spare parts that are required to complete commissioning, including temporary equipment
- Inclusion of the initial costs required to develop the supply chain related to each AR technology, capturing the reduced competition

- Capturing information on the importance of construction site management (e.g., number of supervisors and people, access to documentation, and drawings) as a factor of commissioning success
- Consideration of the variation of regulatory requirements and commitments for acceptance testing depending on the number of plants already demonstrated, affecting the scope

When commissioning experience exists from a previous or running project, this experience should be leveraged to realize any benefits of generic or design-specific lessons learned. The benefit of capturing generic or design-specific lessons learned from previous commissioning experiences could be incorporated into a consolidated database to be available to all stakeholders and included in the CMG. This database could encompass changing procedure content and sequences as well as commissioning spare parts requirements that will improve the accuracy of cost estimates.

Operation

Advanced reactors are expected to significantly deviate from the current LWR fleet with regards to operation resulting from their technology divergence (namely different operating temperatures, pressures, and chemical conditions). AR designs rely increasingly on more passive safety features, increased operational flexibility, advanced automation, and centralized operation of multiple plants (Figure 3-4). Although some load following is already provided by LWRs, the increased flexibility of ARs will lead to additional changes in operation due to inherently designed cogeneration opportunities. This could take the form of process heat, cycling operation to meet power demand, or on/off and load following which will change the operating costs compared to base-loaded plants. The increased flexibility drives design decisions that involve different types of components, component design (relating to parameters like wall thickness), and materials (such as high-temperature steel or ceramics). These changes in operation could affect several factors that influence the operation cost, such as the use of consumables (chemicals, gases), increased labor requirements, oversight, system alignments, surveillances, cost of station services, water cleanup, processing for primary and secondary sides, or waste processing.

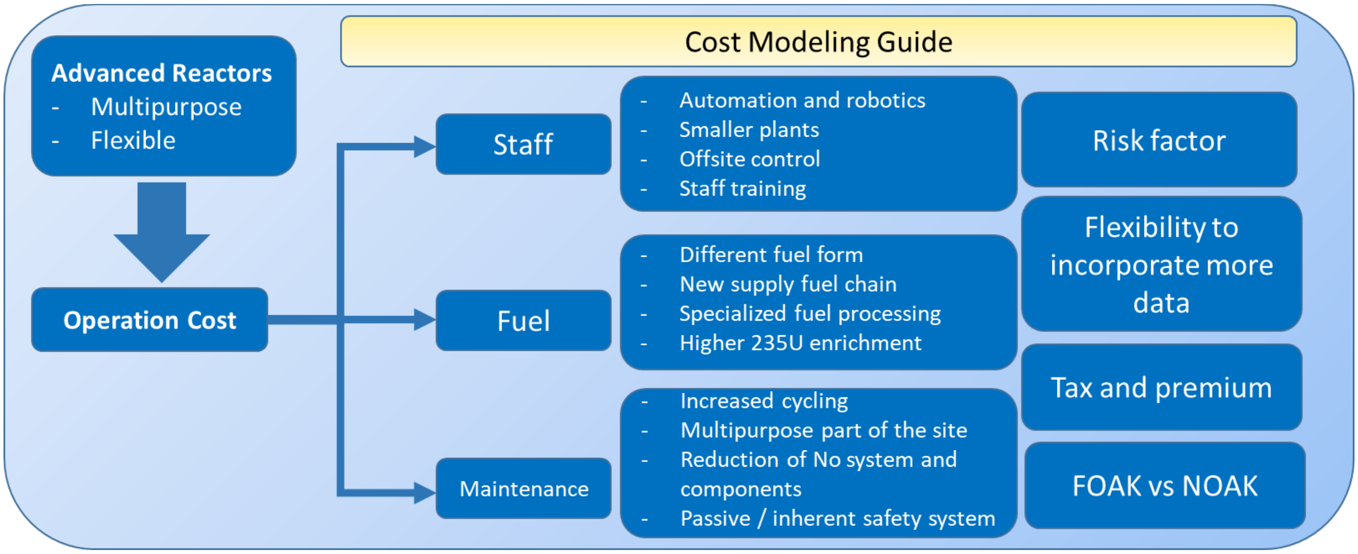

Figure 3-4
Cost Modeling Guide Approach to Operation

The makeup of O&M costs, the majority of which is personnel salaries and maintenance activities, will be drastically changed by the new operating approach. The lack of data on these new technologies currently makes plant operation and maintenance costs hard to estimate. For this reason, it is requinecessary that risk factors be included in the CMG. In this regard, the CMG will be an evolving document that could capture changes in risk in a consolidated database. Some expected changes are discussed below:

- Staff – costs of staff include salary, paid overtime, benefits and retirement, bonuses and incentives, payroll taxes, and training time of licensed and unlicensed operators, security, maintenance, and engineering personnel. Although staffing budget for large LWRs is well known (typical headcount for a full-sized LWR is 800 people), designs with lower output, passive safety features, advanced technologies, remote operation, and/or multiple units have been premised on different staffing models. Smaller plants, the use of automation and robotics, and offsite control/response centers serving multiple units could greatly reduce the staffing number. In the case of microreactors that may have autonomous operation, the staffing is expected to be minimal. Therefore, diverse staffing ranges need to be properly included in a CMG. For the first several units of each particular design of ARs, an additional cost for training operating staff for the new technology and operating regimes and philosophies should be included. An additional indirect cost related to personnel is carrying licensed operators throughout the period of construction delays.
- Fuel – most AR designs are adopting a different form of fuel, ranging from well-established, qualified fuels to unique fuels and configurations that have never been deployed for use. These novel fuels will require a new supply chain including enrichment, specialized chemical processing, fuel fabrication, and fuel shipment. Many designs require higher enrichment than used in the current LWR operating fleets. Fuel reloading frequency will vary greatly, with some designs (like micro-reactors) not intending any fuel reload during the entire life-cycle, while others (pebble bed, circulating fuel molten salt) having continuous refueling with only maintenance-related shutdowns. While maintaining a generic philosophy, initially the CMG

will focus on AR designs with near-term deployment schedules with proven fuels concepts and will evolve over time to include other designs.

- Initial Plant Testing – testing and demonstration will be needed to validate safety claims, and although this testing could be done on a component basis in pre-construction space, it would still need to be verified in-situ during commissioning at least in the first several units of a particular design.
- Maintenance – costs of maintenance include outages, periodic inspection and testing, replacement components, and repairs. Maintenance costs are expected to be reduced substantially by a reduced number of systems and components in AR designs and by the increased adoption of passive/inherent safety systems (e.g., implementation of advanced fuels that are expected to reduce the number of safety-related/significant components). Conversely, flexible power operation (FPO) can increase material degradation of SSCs due to cycling leading to increased maintenance. The CMG should be able to predict these costs and the costs associated with maintenance programs (such as turbine or valve programs).

Non-governmental organization fees (in the US these are entities like the NRC, INPO, and NEI), insurance costs, and taxes from legislation (CO_2 prices and carbon taxes) should also be captured in operation costs. These will be dependent on, but not be limited to, geographic area, resource demands, and time.

An important input for the Guide is the capacity factor; generally, the high capital/low fuel costs typical of LWRs make them best for baseload operation. Plants with high out/high capacity factors generally provide more revenue than those with lower output. However, this might be difficult to predict for a new design due to the diversification of products, lack of operating experience, load following, and varying customer needs. The capacity factor will initially be based on guaranteed values which are expected to change with increased fleet operational experience. The CMG should incorporate capacity factor and turndown range as a cost impact metric and could capture experience going forward in a consolidated database.

Decommissioning

The decommissioning phase includes clean-up of all radioactivity and progressive dismantling of the plant. Currently, a decommissioning fund is established prior to start of operation into which the owner contributes periodically to cover future decommissioning costs. To calculate the decommissioning fund, correlations are available in the literature (in the US, this is in NUREG-1307). However, the decommissioning fund as currently calculated might not be directly applicable to small or advanced reactors.

Advanced reactors bring a new paradigm to decommissioning due to the different coolant and moderator types, reactor size, fuel type and core density, modular construction, and their relation to the radioactive waste stream generated. The cost to prepare the fuel for disposal, which might include changing its chemical form (decomposing or consolidating) and handling, is dependent on the AR technologies. Note that no regulatory guidance is as-yet apparent for long-term storage of AR fuels.

In addition to the broad range of different AR technologies, other factors affect the decommissioning effort and could influence the owner's choices, such as:

- The intended use of land after the plant life
- The possibility of repurposing the site (e.g., reuse of existing transmission infrastructure could provide monetary value)
- The environmental standards and the requirements of the area
- Reprocessing costs and differences between different countries
- Emergent business models such as outsourcing the decommissioning effort to a different owner that acquires the plant before decommissioning.

The CMG should include the possibility to compare these options (Figure 3-5) and ensure a consistent financial approach across the different technologies and procedures, including geographical constraints and requirements in terms of different sites for land use or environmental standards.

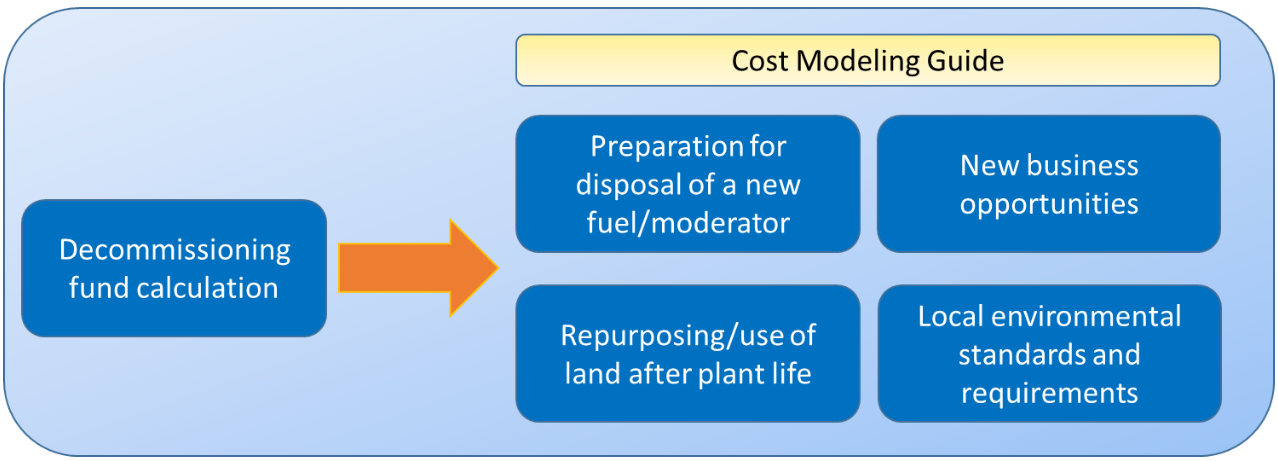

Figure 3-5
Cost Modeling Guide Approach to Decommissioning

4
PATH FORWARD: PROPOSED DEVELOPMENT APPROACH

This scoping study identified the need for a Standard AR Cost Modeling Guide (CMG) that goes beyond a software template, providing guidance on what should be included in a cost estimate and how to assess it. A process needs to be defined to ensure a common understanding of what is required. It should be a framework akin to the Owner-Operator Requirement Guide (ORG), that informs buildup of costs using a standardized hierarchical breakdown of the project and common (standardized) language. Ideally, then, estimates prepared by different people for the same plant or different plants will have sufficient commonality in approach such that lack of agreement on values will be the result of varying opinions or sources of data, not the result of inconsistencies in treatment. The CMG could be used as an input to expand and improve the industry dictionary, as a first step to develop a standard language surrounding nuclear energy.

The next step of the project will be the development of the CMG. As shown in Figure 4-1, work can be divided into two tasks: (1) initial development and trial use of a demonstration level CMG and (2) refinement of Revision 0 based on lessons learned in a pilot application. The figure also shows the need for managing the CMG through its useful lifetime.

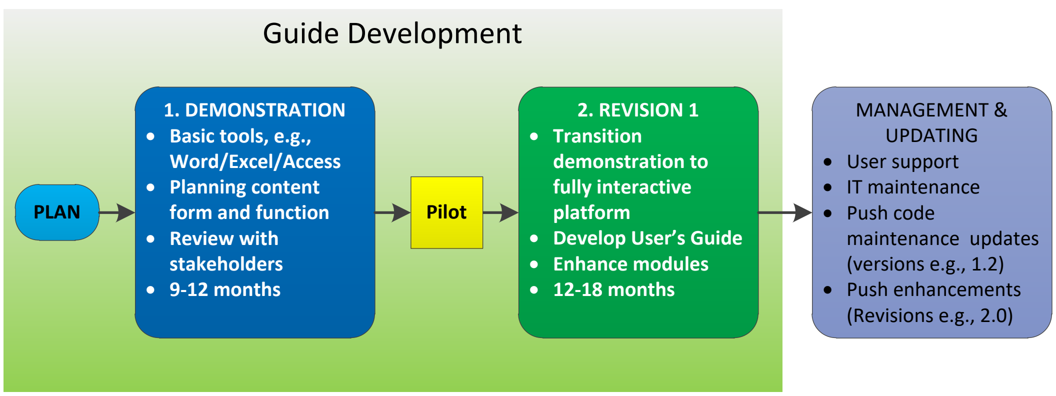

Figure 4-1
Approach to Development and Rollout of Guide

The demonstration task will use feedback from stakeholders provided in the course of this project to inform the content and scope of the demonstration CMG. The second and third tasks will mature in scope over the course of the demonstration task and, as such, will not be discussed in further detail here.

Demonstration Task Scope

The demonstration version, identified as Rev. 0 of the CMG, will be developed using Word/Excel/Access or other standard applications identified at the planning stage.

Nuclear projects involve hundreds or thousands of tasks defined by a Work Breakdown Structure (WBS); however, it can be impractical to manage the project financials using the project management based WBS. To manage costs at an appropriate accounting level and create meaningful financial attributes a Cost Breakdown Structure (CBS) should be used in parallel to the WBS. Together, the WBS and CBS serve as the Rosetta Stone of the project definition. [MD4]The CBS would tie to the WBS in structure. While not as granular as a WBS, the CBS will have sufficient detail to consistently allocate costs to categories that allow meaningful analysis/comparison of different AR technologies on a like-for-like basis. Figure 4-2 is one possible depiction of this concept. The CMG will be based on utilizing a CBS to meet the mission objective.

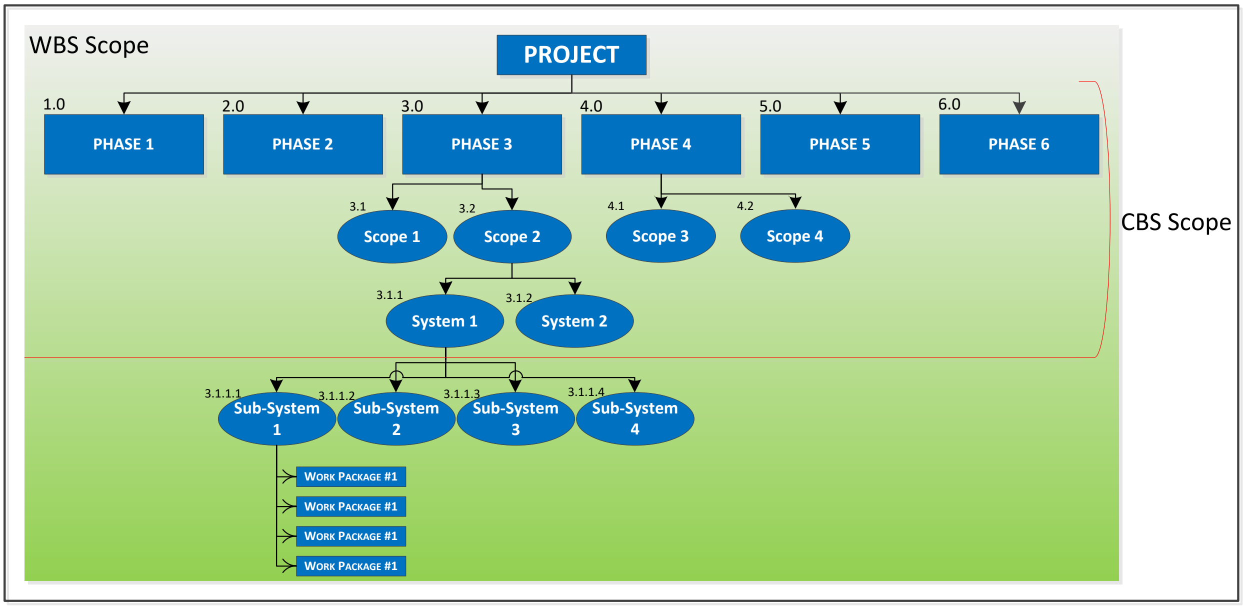

Figure 4-2
Potential Cost Breakdown Structure scope versus WBS scope

The expectation is that the CMG will be comprised of a systematic decision process that informs a cost buildup of a nuclear power development project starting from an initial Owner's planning phase through the life of the project. Figure 4-3 presents the graphical high-level description of this architecture. The figure presents the six high-level phases of a nuclear development project, already discussed in the previous chapter, in chronological order from left to right as follows.

- Planning
- Pre-construction
- Construction
- Commissioning (startup)
- Operation
- Decommissioning

Planning and Pre-construction are the key activities required to define the nuclear project attributes through the life cycle of the plant. Planning is solely the Owner's function. Pre-construction is a Stakeholder's function which at a minimum includes the Owner and targeted AR vendor(s) but ideally should include an Architect Engineer (AE) firm, construction firm, procurement experts, supply chain representative(s), and operator(s). As with all projects, a risk management plan should be developed by the Owner that captures risks in all phases of the nuclear project. Risks will be monetized and incorporated/linked into the cost estimate, e.g., contingency and management reserve. It is expected that the stakeholders will also have their own risk registers that will be shared with the Owner. The Owner will harmonize all of the combined risks with the stakeholders.

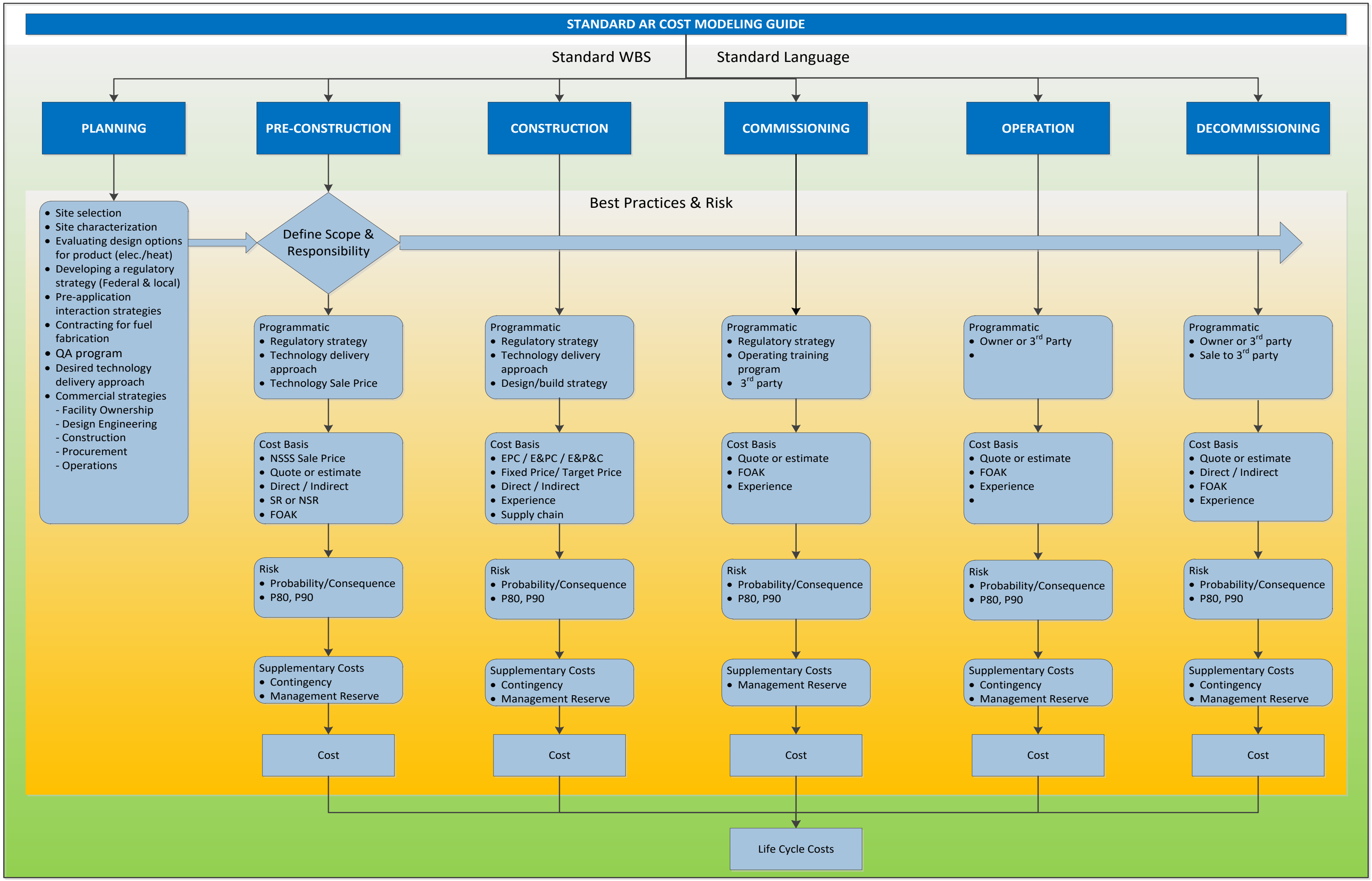

Figure 4-3
High-level potential structure of a Cost Modeling Guide

The development of the demonstration CMG will require the following steps:

- Definition including, but not limited to, selection of tool(s) to be used, form and content, modularization, output type/format, etc.
- Development of CMG mechanics (Figure 4-4)
    - CMG Manual (procedural context, checklists, option selection, automated population of spreadsheets via process modules, etc.)
    - Specialized processing modules (owner's scope costs, AR sale price, supplementary costs, identification and monetization of risk), and
    - Associated cost spreadsheet(s)
- Review draft CMG with stakeholders and update appropriately.

This effort is expected to take nine to twelve months.

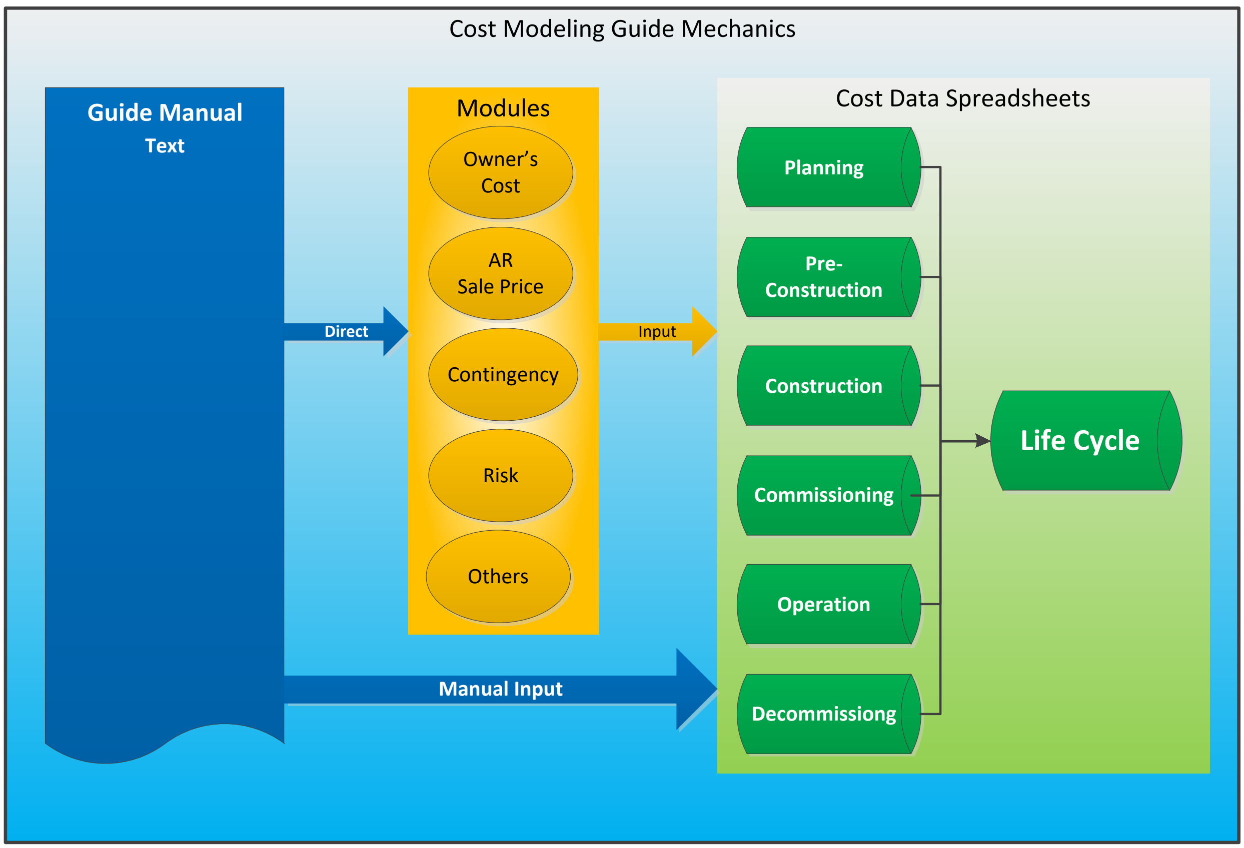

Figure 4-4
High Level Cost Modeling Guide Mechanics

As done with similar projects, such as the ORG, a pilot application of the CMG will be conducted with one or two stakeholders. This would include detailed training for the pilot users. Feedback and lessons learned from the trial use will be incorporated into the development of Revision 1 of the CMG.

Task 2 Scope

Revision 1 of the CMG will build on the demonstration product through lessons learned from the pilot application. In addition, the CMG will be transitioned to a more enhanced interactive process; this could be high-level programming feature options in Access and Excel such as macros or Visual Basic for Applications (VBA) code or developing a completely new standalone application. The detailed scope of this effort will be determined following completion of the demonstration project and insights into the most cost-effective approach for development and future management and updating. This effort is projected to take 12 to 18 months.

Life Cycle Management and Updating

The CMG will be a living document that will require ownership and budgeting for the duration of its lifecycle. As such, EPRI will need to plan for the following through the life of the program.

- Management & Updating
- User support
- IT maintenance
- Push code maintenance updates (versions e.g., 1.2)
- Push enhancements (Revisions e.g., 2.0).

5
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A
MATRIX OF ISSUES AND CHALLENGES

Table A-1
Matrix of Issue/challenges to develop a Standard Advanced Reactor Cost Model

Issue		Basis	Approach/Path forward
1.	**Pre-Construction**		

1.1	Economic impacts of siting near or on an industrial customer's site	- Presence of existing infrastructure may reduce or increase costs:
		  - Avoid need to build new infrastructures if existing infrastructures are re-used or repurposed.
		  - Increase difficulty of construction because of need to work around existing facilities.
		  - If not already part of the plant design, features such as cogeneration or other customizations must be fully included in the cost estimate.
		- Typically costs are calculated per MWh as a rough approximation of necessary electricity prices for full cost recovery on a levelized basis. This might be changed if the plant is designed to have other purposes besides electricity generation.
			- Industrial customers could be stakeholders in building parts of the Advanced Reactor (AR) plant (e.g., steam/hydrogen cogeneration plants on their property).
			- This would require special applications to be incorporated into a standard AR cost model.
			- The participation of other stakeholders in project needs should be properly captured in a standard AR cost model (e.g., including shared costs, increase expense).

1.2	Scope of preconstruction/ financing assumptions	- Preconstruction costs generally include design engineering, site characterization (e.g., geotechnical, meteorological, environmental impact), acquisition of land and rights of way, state and local permitting. - The cost basis is dependent upon the business model under which the power station and reactor technology are deployed. For example, (1) the level of local content if the plant is being deployed in an export territory or (2) if the plant is barge-mounted. - Financial assumptions influence the final cost (e.g., government loan programs and/or private loans). - Different contractual options should be taken into account (e.g., Fixed/ non-fixed/ turn-key contracting)	- Segregation of costs between AR Original Equipment Manufacturer (OEM) and Owner/Operators must be addressed in a standard AR cost model based on scope of AR OEM deliverable. The AR OEM scope will be included in Sale Price and the remaining scope of the plant in Owner/Operator Cost. - The model should try to capture and quantify the impact of broad assumptions and lack of information
1.3	Geographic assumptions	- Labor rates, commodity prices, import/export fees, federal and local permitting/licensing can change based on country, region within the country, and season.	- Segregation of costs between AR OEM and Owner/Operators must be addressed in a standard AR cost model based on scope of AR OEM deliverable. The AR OEM scope will be included in Sale Price and the remaining scope of the plant in Owner/Operator Cost.
1.4	Physical and Cyber Security	- Physical security personnel can be a large part of O&M costs. - Physical security systems are typically part of Balance of Plant (BOP) but cyber security can be partially NSSS OEM-supplied. - Aircraft impact criteria limit structural flexibility and substantially increase costs. - A new Owner/Operator might not have a good understanding of the significant effort involved.	- Cyber security provisions must be addressed both in design by the NSSS OEM and in overall plant design. The former would be included in Sale Price and the latter in Owner/Operator Cost.

Issue	Basis	Approach/Path forward
1.5 Supply Chain	- Nuclear plant supply chains are fragile because of the high cost of maintaining nuclear capability and the current low rate of new build. - Selection of a particular reactor design usually limits possibility of obtaining major components to a single company with attendant lack of competitive pricing and business risk. - Maturity of the commodity supply chain will influence safety-related commodity pricing. - Maturity and expansion of the supply chain is a concern for all stakeholders. - Supply chain maturity is driven by demand, i.e., number of advanced reactor projects securing firm requests and future project bow wave. - Standing up a nuclear supplier from scratch is expensive and risky. - Commercial grade dedication must be part of the tool chest. - Supply chain of skilled craft, especially concerning safety-related systems and components, is currently strained. As with commodity supply chain, it will be driven by demand.	- Supply chain attributes include, but not limited to, commodities and craft labor need to be properly captured in a standard AR cost model. - The best approach to reduce supply chain risk is by minimizing the extent of safety-related equipment.
1.6 Granularity of advanced reactor OEM's Sale Price of deliverable	- Vendors will establish a Sale Price for scope of deliverable which includes design engineering, NSSS cost, material cost, delivery (if FOB destination), certain regulatory, a Design Certification or equivalent, possibly turnkey installation, and profit margin. The Customer (Owner/Operator) does not need the granularity of the buildup of the Sale Price. - The OEM will not provide Sale Price granularity for such sensitive commercially information, nor is it needed for a clearly defined deliverable scope.	- The granularity of AR OEM scope is the key to segregating costs between NSSS OEM and Owner/Operators - Segregation of costs between AR OEM and Owner/Operators must be addressed in a standard AR cost model based on scope of AR OEM deliverable. The AR OEM scope will be included in Sale Price and the remaining scope of the plant in Owner/Operator Cost.

1.7 Nuclear regulation	- Licensing maturity affect several contributors to regulatory costs:
	  - Direct payment for regulator reviewer hours
	  - Applicant time to prepare applications and support analyses and to respond to Requests for Additional Information
	  - Regulatory driven changes to the plant design/operations
	- Regulators throughout the world implement licensing differently; and the standards by which technologies are applied are also varied.
	- Expectation of what jobs the regulatory inspectors will perform and their expectation is commonly unknown and results in substantial delays.
		- Uncertainties in licensing costs for unproven / new technologies or for inexperienced applicants should be taken into account.

2. Construction		
2.1 Roles of engineering and construction	- A breakdown of costs is necessary to judge the reasonableness of the total cost. - Non-AR OEM engineering scope/cost as well as procurement scope/cost will be divided differently depending on the approach used by the Owner/ Operator, e.g., Owner/Operator could secure an Architect Engineering (AE) firm and construction contractor or a turnkey EPC (numerous permutations are possible). - The construction contractor must be incentivized to limit its ability to underbid and make a profit off of change orders. - Accepting a bid that is "too good to be true," that does not have a sufficient amount of information to assess its validity, and/or that puts too much risk on one participant will result in a bad outcome. - The deployment of off-site modular construction techniques as opposed to 'stick-build' might have a fundamental influence on costs and should be considered (see 2.6).	- It should be clear if the AR OEM includes a turn-key installed product in the Sale Price or if construction costs are not included. - Segregation of engineering and procurement costs must be addressed in a AR standard cost model based on approach used by the Owner/Operator.

Issue		Basis	Approach/Path forward
2.2	Approach for determining capital costs	- Capital costs include the preconstruction costs, direct costs, indirect costs, project contingency, and management reserve. - ARs are at various levels of development and have various levels of experience, history, test data, etc. This contributes to uncertainty of costs.	- It should be specified if owner's costs are included in the estimates (e.g., land, site work, project management, administration, startup costs, taxes, and insurance.) - The basis for the project contingency and management reserve should be explained.
2.3	Estimating direct construction costs	- Direct costs for the reactor plant are associated with all equipment, materials, and installation. - Direct costs for balance of plant and for civil work generally exceed those of the reactor plant for existing large reactors. - Direct costs are comprised of several fundamentally different activities, each with its own characteristic spend curve and sources of uncertainty that should be included in the cost model.	- The structure of contracts will determine who bears the risk and needs to be properly captured in a standard AR cost model.

2.4	Estimating indirect construction costs	- Indirect costs include the capital required for construction overhead and other costs not included in the direct costs such as:
		  - EPC contractor internal management and supervision
		  - Project management (e.g., oversight of EPC contractor)
		  - Regulatory (e.g., direct licensing charges such as NRC labor, licensing support such as analysis and document preparation, legal)
			- The risk profile needs to be properly captured in a standard AR cost model.

2.5	Cost of standardization	- Standardization drives cost savings by reducing the need for site-specific engineering, in turn reducing the quantity and scope of change orders and hence lowering labor costs, enabling faster construction, and allowing for greater competition within the supply chain.	- The AR OEM's Sale Price should reflect these savings in a competitive cost (see 1.7) and savings realized in the Owner/Operator costs.

2.6	Impact of modularization	- Modularization has benefits but introduces risks, both of which need to be factored in the cost model:
		  - Extent can vary from a limited number of skid mounted subsystems to a whole microreactor delivered ready to start. The cost/risk balance is crucial to model for the territory in between.
		  - The model for power plant construction shifts from conventional stick build field construction to mass production (in shop facilities) and rapid in-field assembly.
			- Expected benefits:
			  - Permanent work force at modularization facility reduces hiring, training, and relocation costs and improves quality, minimizing rework.
			  - Reduced vulnerability to weather-caused fabrication delays.
			  - Improved access and environment for work and inspection speed tasks and reduce rework.
			  - Modules can be completed and stockpiled ahead of need (just in time delivery), reducing vulnerability to work stoppages and delivery risk.
			- Known risks:
			  - Critical path dependent on timely delivery of usable (i.e., documentation shows met all specs) modules, reducing flexibility to work around delays.
			  - Module shipment: added cost, route limitations may not support transfer of some modules, potential for damage.
			  - Performing substantial work away from site reduces local community economic motivation to support project.
			  - Establishing a new fabrication facility requires large investment, instilling nuclear culture, and introduces economic risk if rate of receipt of orders does not meet plan.
			  - Tight tolerances needed to ensure proper fit-up increases costs

2.7	Construction duration	- Construction duration affects the cost of financing during construction. - Construction delays add costs on top of the overnight cost, in the form of inflation and financing charges. - Scheduling of construction activities, management of construction activities, QA, and inspection, effective change procedure play a role in the final duration and cost.	- Depending on the model used for Sale Price (see 1.7) these costs could be all inclusive in the Sale Price or split. In either case the Owner/Operator ultimately bears the cost. - The risk profile is different and needs to be properly captured in a standard AR cost model.

Issue		Basis	Approach/Path forward
2.8	Cost estimate accuracy	- Historically, nuclear project cost estimates have been very optimistic. - Every cost model projects an estimate. The estimate has an expected accuracy range based on the level of project completion. - The commissioning of a First-of-a-Kind (FOAK) plant will be significantly different from that of an Nth-of-a-Kind (NOAK) plant due to inexperience and extent of Validation and Verification program requirements for initial deployments.	- A standard AR cost model should accommodate multiple estimate class levels. - The cost model is considered a tool primarily for use by the Owner/Operator. An Estimate Class Level 2 or 1 would be the most useful for evaluation. - A standard AR cost model should consider an experience factor that is normalized based on MWt to be applied to subsequent projects.
3.	**Commissioning**		

3.1	System turnover from construction	- Turning over systems on time per schedule is necessary to avoid cascading delays and loss of worker efficiency.
		- Presence of flexibility built in the design to meet regulatory expectations in case of unexpected commissioning issues.
			- As construction work nears completion, components and systems must be turned over from construction to the plant testing organization as follows:
			  - Systems as a whole
			  - Parts of systems (needed to perform specific tests)
			  - Areas of the plant
			- Workflow planning and project controls must be mature to minimize risk and costs appropriately captured in a standard AR cost model.

3.2	Commissioning approach	- Applying commissioning experience from one project to the next irrespective of participants is essential in order to realize any benefits of lessons learned from similar technology (and generic from other designs). - Commissioning activities must be performed by the operating organization's licensed operators in accordance with formal procedures developed by or with assistance from various OEMs. - This might be influenced by Part 50 vs Part 52 approach, with the latter having Inspections, Tests, Analyses, and Acceptance Criteria (ITAACs). - Regulatory requirements/commitments for acceptance testing may vary with the number of plants already demonstrated and, as such, affect the scope/ cost the Initial Test Program (ITP).	- Capturing lessons learned from previous commissioning for a particular design should be incorporated into a standard AR cost model. This could include changing procedure content and/or sequences as well as commissioning spare parts requirements that will improve accuracy of cost estimates. - Initial discussions with an AR OEM should determine how prior commissioning lessons have be addressed in order to achieve a reduction in commissioning cost. - The Owner/Operator should capture experience from its projects and provide it for inclusion (by EPRI and/or NEI) in a consolidated database.
3.3	Spare parts warehousing	- Spare parts are generally included in the owner's costs. - A fleet approach should be considered in which an AR OEM and/or Owner/ Operator (or consortium of Owner/Operators) maintain commissioning spares and recommended spares warehouse(s). More favorable commercial terms could be negotiated to only pay for parts used with a "member" fee.	- Model should include costs for all estimated additional equipment, spare parts, etc. that are required to complete commissioning that may not be within EPC scope due to being temporary equipment. - A fleet approach could be a company or a design-based approach that would bring more companies into a single pool of spare parts which would further minimize spare parts cost

Issue		Basis	Approach/Path forward
4.	**Operation**		

4.1	Predictability of O&M costs	- The primary contributors to O&M costs are:
		  - Staff: licensed and unlicensed operators, security, maintenance, and engineering
		  - Fuel: type and refueling requirements
		  - Maintenance expenses: periodic inspection and testing, replacement components, and repairs.
		- For non-LWR or low output reactor designs, O&M costs are difficult to predict until an experience base is established.
		  - Staff: advance reactors consists of a variety of designs with different staffing requirements. Demonstration plants are needed to confirm staffing needs (see 4.2 for detailed staffing items).
		  - Fuel: most AR designs use HALEU in unique configurations requiring a new fuel supply chain including enrichment, fuel fabrication, and fuel shipment.
		  - Maintenance: extensions of current technology to new configurations and implementation are significant deviations from experience.
			- A standard AR cost model should compensate for lack of experience in a consistent, defined approach.
			- A standard AR cost model should compensate for a diverse range of technology-based maintenance cycles for repair/replacement of high-cost SSCs.
			- A standard AR cost model should compensate for cost of various modes of operations: powering down to hot /cold shutdown, powering up from hot/cold shutdown, load following of the diverse AR technologies. This cost would include consumables (chemicals, gases, etc), extra manpower, oversight, system alignments, surveillances, cost of station service, water cleanup and processing for primary and secondary sides, waste processing, auxiliary boiler, etc.
			- Maintenance-related costs associated with control rods, valves, controls, heat exchangers and other components subject to wear should be accounted for in a standard AR cost model.
			- Costs associated with programs such as SG program, Offsite Dose Calculation Manual (ODCM) effluent programs, turbine programs, valve programs, etc. should be accounted for in a standard AR cost model. The EPRI “Flexible Power Operations—Guideline for Assessing Costs”, EPRI 3002017334 may be of value.
			- Required inspection and oversight, effective operating procedures, and effective inspection processes should be properly defined and captured in a standard AR cost model.

4.2	Staffing requirements	- Staffing costs include salary, paid overtime, benefits and retirement, bonuses and incentives, payroll taxes, and training time. - Although the staffing budget for large LWRs is well known, designs with lower output, passive response, advanced technologies, and/or multiple units have been premised on different staffing models. In the US, some vendors have discussed staffing with the NRC, but none have yet built and operated a plant to demonstrate sufficiency. - The typical headcount for a full-sized nuclear plant (around 1000 MW) is 800 people. Operators and maintenance staffing is expected to be reduced for SMRs and micro-reactors. Automation, robotics, and offsite control/response centers serving multiple units are expected to reduce staffing needs. - Security staffing, which is generally the second largest group after operators, is also expected to change from that currently used. - Staffing is second to cost of fuel in terms of impact on O&M costs. In the case of micro-reactors that may have autonomous operations, the staffing is expected to be minimal.	- Diverse staffing ranges need to be properly captured in a standard AR cost model. - Proper training ahead of time should be performed to get the operating staff ready for a unique FOAK AR.
4.3	Security	- Security (primarily labor) makes up a big portion of O&M costs. - Future security may rely more on autonomous devices or reduced vulnerability. While these may reduce security personnel they carry an O&M cost that may not be insignificant. - Diverse security system designs and security staffing offsets need to be properly captured in a standard AR cost model.	- A standard AR Cost model should capture the diverse range of security to be used in the future.

Issue		Basis	Approach/Path forward
4.4	Fuel type	- Most designs are adopting a different form of fuel. Plans range from well-established, qualified fuels to ones that require further testing, have never be deployed for use, or are difficult and expensive to source and fabricate. - Most designs also require higher enrichment up to 5% 235U or high-assay low-enriched uranium (HALEU) to just below 20% 235U. - Frequency of fuel reloading will vary between AR designs with some, primarily micro-reactors, not requiring any fuel reload during the life cycle of the reactor and others (e.g., pebble bed, circulating fuel molten salt) having continuous refueling without shutdown. - Specialized chemical processing for fuel may be required for certain advanced reactor designs.	- Periodicity of fuel reloading and specialized fuel processing need to be properly captured in a standard AR cost model. - It is expected that Owner/Operators will only be contemplating AR designs with near-term deployment schedules. As such, unproven fuel does not need to be modeled in a standard AR cost model.
4.5	Safety systems	- Increased adoption of passive/inherent safety systems and advanced fuels is expected to reduce the number of safety-related/significant components, which lowers capital and O&M cost. - New designs aim to reduce both capital and O&M cost by substantially reducing the number of systems and components in them.	- A standard AR cost model must have the ability to allow adjustment for number of safety components. - A standard AR cost model must have the ability to adjust costs based on relative simplicity/component count.
4.7	Costs associated with legislation and Non-Governmental Organization (NGO)	- Legislation (e.g., CO_2 prices, carbon taxes) are expected to change with time and could affect the competitiveness of advanced reactors. - In the US, NRC, INPO, and NEI fees are included in O&M costs.	- Legislative and required NGO costs need to be properly captured in a standard AR cost model.
4.8	Mode of operation and expanded flexibility	- Many AR designs will have Flexible power operations (FPO) and load-follow capabilities that will affect O&M. - Cogeneration/alternate energy production equipment adds to capital cost but provides a second source of revenue and the ability to rebalance output to enhance revenue.	- A standard AR cost model should accommodate FPO and load follow cost impacts.
4.9	Capacity factor	- The high capital/low fuel costs of nuclear reactors generally make them best for sustained high power operation. Plants with high capacity factors generally provide more revenue than those with lower output. - Capacity factor is difficult to predict for a new design and will initially be based on AR OEM guaranteed values. Increase fleet operation will help establish a better value.	- A standard AR cost model should incorporate capacity factor and turndown range as a cost impact metric and capture experience going forward in a common lesson learned database.
4.10	Maintenance	- FPO can increase degradation of SSCs. - The current LWR nuclear reactors are typically designed for baseload operation. Most advanced reactor designs are suited for load following. Aggressive turndown rates could introduce some degradation due to cycling. However, it is expected that the advanced reactor OEMs have considered this operational impact and have either chosen appropriate materials or have operating limits defined to minimize the effects.	- A standard AR cost model should consider potential impacts of FPO and incorporate benefits as a metric. Costs that are variable rather than fixed should be clearly captured to show potential cost savings if power is reduced.
4.12	Operational safety	- ARs tend to incorporate passive and inherent safety systems as opposed to active systems.	- Testing and demonstration would be needed to validate the safety claims of AR OEMs. This testing could be done on a component basis in pre-construction space but would still need to be verified in situ during commissioning, at least in first several units of a particular design.

Issue	Basis	Approach/Path forward
4.13 Different operating conditions	- Technologies that operate at different temperatures, pressures, and/or chemical conditions drive design decisions that involve different materials (e.g., high temperature steel), component parameters (e.g., wall thickness), and types of components (e.g., blowers instead of pumps). The cost model needs to be able to input these variables to more accurately determine the cost impact of design choices. - Advanced reactor fleets may have different operating models such as centralized operation of multiple plants.	- A standard AR cost model should allow for O&M reductions for plants the demonstrate possibility of remote operation.
5. Decommissioning		
5.1 Scope of decommissioning	- Advanced reactors bring a new paradigm to decommissioning of nuclear plants. Micro-reactors may not need any significant decommissioning and will either transported from the site or buried in place. - Size of components and core size/density will also affect decommissioning costs. - Different sites have different requirements for land use or environmental standards after decommissioning.	- Decommissioning needed for ARs that were assembled with modular components should have a simpler decommissioning process than non-modular designs. - A standard cost model should capture modularity in decommissioning. - Intended use of land should be considered in advance to determine the level of cleanup required.
5.2 Scope of used fuel handling/disposal	- Handling/disposal of used fuel will be different for different advanced reactor technologies. For example, a liquid-fueled MSR could use fuel taken from an operating reactor in the core of a new reactor. Additionally, additional costs to prepare the fuel for disposal (e.g., changing its chemical form) may be associated with different advanced reactor fuels.	- Model should consider used fuel costs and the variety of options a plant may provide (ex. similar to the current fleet, breeding reactor that has less waste, reactor that reuses depleted fuel, etc.). - Model should allow for possibility of repurposing site at end of life (e.g. reuse of existing transmission infrastructure could provide monetary value).
5.3 Decommissioning Fund Calculation	- Formulae are available in the literature (e.g., NUREG-1307) but may not be directly applicable to small or advanced reactors, as they are based on a reference PWR and BWR model. - Guidance ensuring a consistent financial approach across different technologies should be incorporated into a standard AR cost model.	- Decommissioning cost should be included in the initial design and captured in a standard AR cost model.
A. Digital engineering and "Common Information" model	- The use of digital engineering, such as digital twins, would reshape the way a plant is designed, constructed and operated, with a significant effect on a cost model.	
B. Cost models should consider maturity of design, experience and the stake of the participating organizations, size of the project, and regulatory status.	- A large number of inter-related factors affect the cost and uncertainty for project. Schedule has the single largest impact on actual project costs. Because of their complexity, nuclear new build projects have long development times that magnify cost and schedule risk.	- A project contracting structure should place responsibility for specific activities with organizations with experience in those activities. - The major organizations involved in a project should have an economic stake in its success and the overall risk needs to be shared.

C. Roles and responsibilities	- Traditional scope of NSSS OEM has been nuclear island design and major equipment with EPC being the Owner/Operators responsibility.
	- A new paradigm must be embraced by all stakeholders (advanced reactor OEMs and Owner/Operators); providing a completely installed product. In this regard, many other organizational relationships are possible:
	  - The OEM leads the project team, including the construction contractor, to deliver a complete, working plant. However, OEMs have little or no experience with construction and inadequate resources to take on such a large role.
	  - The Owner acts as general contractor, managing the OEM, construction, and operating contractors.
	  - The Owners place an EPC contract with a construction company, which is responsible for having the OEM provide the design, components, and procedures.
		- Experience has shown that costs are best controlled by:
		  - Clear and complete definition of roles and responsibilities.
		  - Establishing a project team with experts from the OEM, constructor, component fabricator, owner, and operator companies at the very outset
		  - Ensuring free and open communication of project cost, schedule, and technical information.
		  - Using the expertise/experience from project team members to optimize fabrication and construction.
		  - Getting to a true standard plant (i.e., interchangeable parts, common procedures) as quickly as possible.
		  - Maintaining and effectively using a common lessons learned database.
		A contracting arrangement that rewards performance but minimizes opportunities for renegotiation.

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