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Challenges and Opportunities for New Nuclear Construction: Lessons Learned - but Not Followed

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Abstract:

Nuclear Energy is viewed as part of the solution for global climate change. However, capital costs are high, and the recent experience of new construction has generally not been very good as evidenced by projects in the United State, United Kingdom, France, and Finland. There are examples of successful projects with nuclear plants in the United Arab Emirates, South Korea, and China. There are many studies focused on lessons learned from these past successes and failures. The principal root cause of most failed projects is the underestimation of the difficulty of building such complex and first of a kind (FOAK) facilities and developing unrealistically optimistic budget and schedule plans to begin with. We define failure not at completing the project but as failure in meeting cost and schedule objectives set forth when the project was originally proposed and when the plant begins generating electricity.

For a nation contemplating building its first nuclear plant such as Poland or a nation with an established nuclear program such as the United States or France, the lessons learned are quite similar in many fundamental ways. For new nuclear power nations, the challenges are even greater especially in dealing with a new regulatory system, safety culture, supply chain, quality, configuration management, document control, and qualified work force. Public support or opposition can pose additional challenges since it can affect how effectively plans can be implemented, especially in dealing with regulatory bodies and local political opinion. A key industry lesson learned is that FOAK organizations present greater challenges than FOAK technical issues….creating effective global teams is easier said than done.

This paper will highlight some of the challenges and successes of past projects as documented in many studies which will be found in the references section. We will also highlight what we see as a success path for a new nation thinking about how to do this effectively. The most recent successful construction and deployment project is that of the United Arab Emirates which has built 4 new nuclear within reasonable cost and schedule targets. South Korea and China are other countries worthy of review since they have been able to build nuclear plants within reasonable expectations of schedule and budget.

TABLE OF CONTENTS

Introduction:

While international bodies such as the Intergovernmental Panel on Climate Change call for the rapid expansion of nuclear energy to address the global climate change challenge, the needed expansion of nuclear power is not proceeding as fast as hoped or needed. This is largely due to the high cost of building new nuclear plants (NNP). This is based on recent experience of NNP cost and schedule overruns by massive amounts – sometimes 3 to 4 times the expected costs when the projects were initiated. There are many studies that have looked at recent projects that have experienced cost and schedule overruns and those that have shown better performance. Table 1 shows common characteristics of recent NNP projects that are found in low and high-cost plants [1,2].

Table 1

Common Characteristics in Low and High Cost Nuclear Construction Projects (ETI, 2018 Appendix A)

Low Cost Plants	High Cost Plants
• Design at or near complete prior to construction • High degree of design reuse • Experienced construction management • Low cost and highly productive labour • Experienced EPC consortium • Experienced supply chain • Detailed construction planning prior to starting construction • Intentional new build programme focused on cost reduction and performance improvement • Multiple units at a single site • NOAK design	• Lack of completed design before construction started • Major regulatory interventions during construction • FOAK design • Litigation between project participants • Significant delays and rework required due to supply chain • Long construction schedule • Relatively higher labour rates and low productivity • Insufficient oversight by owner

Designing and constructing a NNP is a "FOAK Megaproject" that many planning stakeholders fail to completely appreciate.

- All Megaprojects typically cost over $US 1 Billion; may be FOAK; are complex; are of long duration; are highly visible politically; are supported by passionate advocates; have high risk and an "optimism bias" that sometimes blinds the developers and investors.
- An NNP in a new country is always a FOAK where they cost over $US 5 Billion and are accompanied with different and more demanding regulatory requirements and a culture of accountability that far exceeds that in non-nuclear industries.

- There are many megaprojects that have similar delays and cost overruns especially with infrastructure projects such as roads and bridges, tunnels, etc. Typically project costs are understated and project schedules optimistic hoping that they can be achieved. Project sponsors are reluctant to spend too much money upfront, prior to the commitment to build. They do not do sufficient design and engineering as well as risk analysis fearing that the actual numbers may to too high to gain project approval. The goal is to get started on the project and engineer as you do the construction work. [3,4] This is a key lesson learned and critical mistake.

There is also the FOAK challenge of setting up a company or engaging several companies and subcontractors who need to find a qualified workforce that can number in the thousands in a relatively short time with the management skills needed for nuclear grade work. Organizing an integrated project team (IPT) is perhaps one of the biggest challenges facing utility owner/licensee leaders. They need to work seamlessly with several major contractors, subcontractors and vendors. They need to Identify qualified contractors and vendors to establish trusted relationships specifying detailed contract terms and commitments. They need to verify the quality of service and manufactured goods that must be thoroughly checked and documented to nuclear grade acceptance standards. Documentation is a major challenge for nuclear construction. Then, there are the multiple labor unions who can make or break a project. Again, creating effective global teams is easier said than done.

There have been many lessons learned studies conducted on past nuclear projects by reputable and unbiased organizations seeking to better understand what works and what doesn't work. This includes studies by the National Academy of Sciences, the United Kingdom Royal Academy of Engineering, the Nuclear Energy Institute (NEI) in United States, the Electric Power Research Institute, the Massashusetts Institute of Technology to name just a few. Companies have also performed many self-assessments to determine what went wrong and how to improve. Unfortunately, since the number of NNP projects in the western world is so few, those lessons have to be re-learned by new management teams, contractors and vendors. Countries such as China and Korea with a sustained nuclear programs have been successful due to continuing to build new plants and being able to maintain a work force that can move from site to site and using a reliable and steady supply chain. [9,10,11,12]

Recent Experience:

We shall briefly review several nuclear projects that have not met the expectations of the customers and highlight some of the chief reasons.

Vogtle Nuclear Power Station (US) –Units 3 & 4, each 1,200 Mwe Westinghouse AP-1000

Start Date: 2009 Initial Operating Date: 2016/2017 Commercial Operation: 2023/2024

Initial Project Cost: $ 14 Billion Final Project Cost: $ 30 Billion

This project along with the Summer twin unit nuclear plants were meant to be the start of the nuclear renaisance in the United States. Building off the NRC "certified" Westinghouse AP 1000 design, this two unit project was to be a standardized Westinghouse innovative new reactor "passive safety" plant design

that greatly eliminated many components, engineered safety syatems, and miles
of cabling and piping in the hopes of reducing construction and operating costs. Modularity principles were introduced in construction and containment design. This plant was also the first to go through the new "streamlined" licensing process using the 10 CFR Part 52 in which a combined operating license and construction permit was to be issued after licensing review. The trouble with this concept began early with an incomplete detailed design and a new licensing process that was much more demanding in terms of changes to the "certified" design license. Secondly, it was a FOAK non-standard reactor. Thirdly, we had a FOAK organization structure based on a total project fixed price contract. Thus, we had three concurrent risks – first of a kind design with first of a kind organization in a first of a kind licensing process with an incomplete design.

Due to these factors, significant delays and cost increases occurred. Mistakes were made in the beginning with the digging of the foundation and backfill that was not up to regulatory standards. Second, the plan for factory manufacture of key structural components by the Shaw Nuclear Services Facility lacked sufficient nuclear experience to meet nuclear grade construction standards and quality requirements. This facility to was to manufacture key parts of Westinghouse's AP 1000 plants in the US and China. Also, NRC standards changed during the construction due to the 9/11 terrorist attack on the US World Trade Center requiring significant redesign of many of the structural and design features of the plant causing costly delays. Due to the lack of new nuclear construction in the US, there was also a shortage of a qualified nuclear workforce and nuclear qualified vendors in the supply chain which further complicated the execution of the project. On top of all that was the COVID pandemic which seriously disrupted all activities on a worldwide scale. The Fukushima nuclear accident also caused detailed "stress" tests of all existing reactors and new designs.

There were also significant alignment challenges between Westinghouse, Shaw and other vendors in terms of who was in charge resulting in legal contract issues that slowed progress and lacked the cohesiveness needed for successful project execution. The cost overruns finally caused Westinghouse to declare bankruptcy which added additional costs and complications to completing the project.

There are many reports and news accounts of the Voglte struggle which does have a happy ending in that Vogtle has started making electricity, albeit late and way over budget, in 2023. The good news is that the plant is expected to operate for 60 years. Readers are encouraged to seek out these reports especially for a nation building its first nuclear plant such as Poland. [5,6]

In summary, first of a kind projects are expected to take longer than estimated, cost more than estimated and will run into technical hurdles in an unsure regulatory and political climate even under the best project management organization. Nuclear standards are exacting and a strong quality assurance culture is required by all parties. Beginning a project with a completed detailed design (at least 90 – 95%) is a must.

Olkiluoto, Finland – 1,600 Mwe European Pressurized Water Reactor (EPR)

Start Date: 2005 Initial Operating Date: 2010 Commercial Operation: 2023
Initial Project Cost: 3 Billion Euro Final Project Cost: 11 Billion Euro

This project was to be the first new nuclear plant to be built in Europe of a new design intended to increase plant size to 1,600 Mwe to improve its economics while also improving safety. It also was a “first of a kind” reactor being built at a site that already had 2 reactors. AREVA bid the plant as a “turnkey” project with a fixed price which became part of the problem in terms of getting the plant built with the spirit of cooperation needed by the owners (TVO) and AREVA, the main contractor at the time. The EPR’s detailed design was also not complete in a country whose national regulations were not completely understood by the contractor which caused the first major delays in the pouring of the basemat concrete. There were other significant problems that caused additional delays such as fabrication of the huge reactor vessel, welding on the steel containment liner and the instrumentation and control system to name but a few [7]. A detailed report by the Finish regulator STUK highlights some of the problems found at Olkiluoto. [8]

The key to the problems identified were a lack of safety culture by the contractors, lack of qualified qork force, poor planning and supervision by AREVA, a company that lacked nuclear construction experience. There were also manufacturing difficulties of key components requiring rework, and the lack of a complete detailed design approved by the regulator as primary causes of the delays. [13]

These problems led to lengthy contract disputes about cost which ultimately caused AREVA to be sold to EDF to complete the project.

Flamanville, France – 1,600 Mwe European Pressurized Water Reactor (EPR)

Start Date: 2007 Initial Operating Date: 2012 Commercial Operation: 2024
Initial Project Cost: 3.3 Billion Euro Final Project Cost: 13 Billion Euro

The Flamanville nuclear plant’s delays were also the result of an incomplete detailed design but were confounded by problems with the pouring of concrete, rebar locations, steel containment liner welding, problems with manufacture of certain components of the steam generator. Additonally an inspection of the reactor vessel closure and bottom at the Japanese factory in 2015 discovered anomolies which the regulator required to be replaced by 2024. Since the plant was not able to start up as scheduled in 2017, a major setback in the start of operations was avoided by a decision of the regulator to allow for the start of operation despite these reactor vessel “anolomies”.The reactor vessel head will have to be replaced in the future. There were numerous inspections by the French regulatory (ASN) which led to suspensions of work by the contractors. Similar problems to those of Olkiluoto were also found with design of the instrumentation and control system. These problems are indicators of poor management oversight of construction work and that of the outside vendors. [14]

There are other projects that could be reviewed but the lessons learned will be similar with different specific initiating events.

Next, we shall review several success stories in which the customer was satisfied, highlighting some principle reasons.

Barakah, United Arab Emirates – 4 Units 1,345 Mwe APR 1400 Pressurized Water Reactors [39]

Start Date: 2012 Initial Operating Date: 2017 Commercial Operation: 2020/2021/2022/2024
Initial Project Cost: $ 20 Billion Euro Final Project Cost: $24.4 Billion

Table 2

Reactor Name	Model	Reactor Type	Net Capacity (MWe)	Construction Start	First Grid Connection
Barakah 1	APR-1400	PWR	1,337	2012-07	2020-08
Barakah 2	APR-1400	PWR	1,337	2013-04	2021-09
Barakah 3	APR-1400	PWR	1,337	2014-09	2022-10
Barakah 4	APR-1400	PWR	1,337	2015-07	2024-03

Table 2 summarizes this 4-unit Barakah Project. This project is now a model for new builds in countries that do not have existing nuclear plants or a regulatory system to support nuclear power. The UAE, early on, decided to engage the International Atomic Energy Agency (IAEA) and other regulatory bodies such as the US Nuclear Regulatory Commission to help develop a regulatory body (Federal Authority of Nuclear Regulation FANR) capable of reviewing and approving license applications in conformance with international safety standards. Additionally it created a separate company (Emirates Nuclear Energy Corporation (ENEC) to oversee the competitive bidding process to select a design to build four large Generation IV nuclear plants. [15] This company would ultimately also oversee construction. Their decision process was informed by independent outside consultants which resulted in the selection of the Korean standard APR1400 that had been built in Korea and has operated successfully.

The prime contractor, KEPCO is in a consortium with Korea Hydro & Nuclear Power (KHNP), Hyundai Engineering & Construction, Samsung C&T, and Doosan Heavy Industries & Construction. KEPCO is in charge of the design, construction and will help operate the four units making clear that it is responsible for aspects of design through operation. This was a identified strength of the project since there was someone that had ultimate responsibiliy for cost and schedule. The contract also included training and education development for UAE to take over operation through it new operating company (NAWAH Energy Company). This company is a joint venture between ENEC and KEPCO indicating further mutual interest in success. The price for the four units was also very competitive with a demonstrable ability to deliver the plant as was shown for the Shin-Kori 3 and 4 reference plants. At one point over 20,000 people from many countries worked on the Barakah site which in itself is a management feat worthy of attention for future projects

The APR 1400 design was a Combustion System 80+ design certified by the US NRC
and the Korean regulator. The UAE regulator, FANR, developed its regulatory system along the lines of the US NRC and the IAEA. ENC referenced the Korean regulatory reviews in it licensing documentation.

Despite all the experience with building nuclear plants in Korea and elsewhere, all four units found cracks in the concrete containment structure causing significant delays which required repair. These cracks (more likely voids) occur when concrete solidifies too fast during the continuous pouring process. The other reason for delay to startup of the first reactor, even though construction was essentially complete, was an operational readiness audit by the regulator that found that the crews were not ready for operations requiring about an 18-month delay. FANR had raised 400 adverse findings in a review requiring rectification of various technical organizational and management issues. [16,17,18,19]

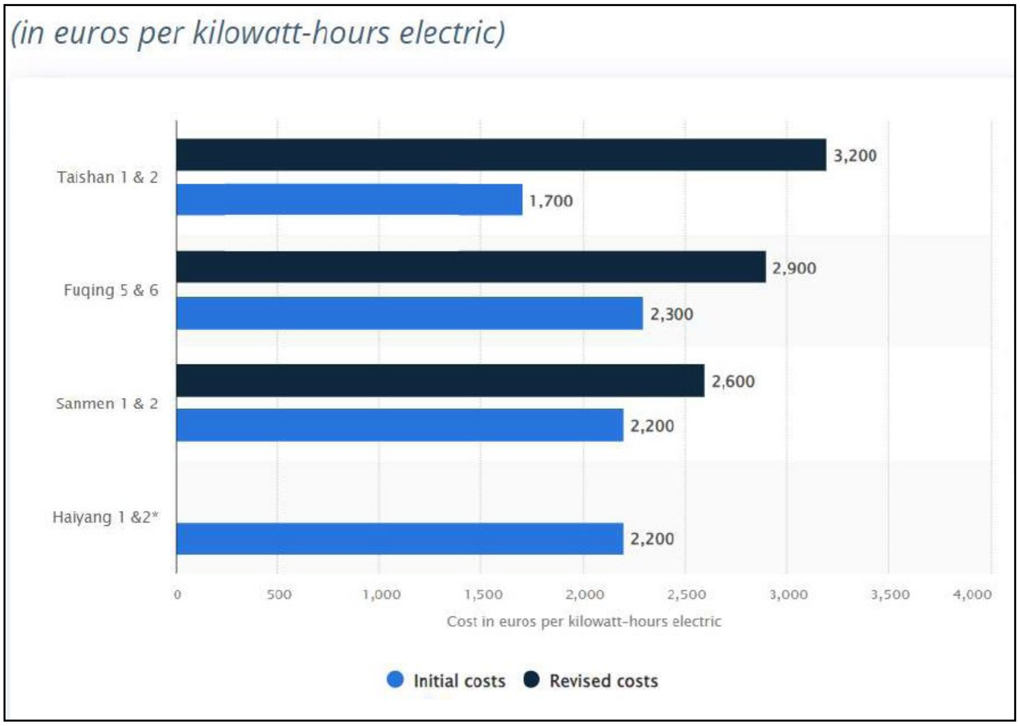
China

China has the largest nuclear expansion program in the world today. Over 50 reactors have been built and are operating and as many are planned for the future. While China started its nuclear program with an 800 MWE French designed nuclear plant in the late 80’s, it has since contracted with Westinghouse to build AP1000’s and with AREVA/EDF to build uprated Evolutionary Power Reactors (EPRs). Both designs have completed their construction and are now operating. Not much is known about delays but many are due to faulty components some originating outside of China and some within due to its localization program. China has successfully copied some of these western designs and upgraded them to Chinese version such as the CPR- 1000 and CAP 1400 with the cooperation of the original vendors.

The Figure 1 below shows some of the recent cost experience with Chinese new builds in terms of original cost estimates compared to final delivered cost in euros per kwhr. This costs include the cost of financing, commissioning and operations and maintainance to reflect the total cost of power. [20]

Figure 1

Initial and Revised Construction Cost[1]
Modern Nuclear Reactors Operative in China in 2021



The Taishan plants are EPRs, the Fuqing plants are Chinese design CPR 1000 based on the original French 800 Mwe reactors, while the Sanmen and Haiyang plants are AP1000 type. All four AP 1000 plants were started about the same time and went into commercial operation in about 9 years. What can be inferred by these charts is that for the EPR units, the same problems existed as existed in France and Finland. The construction performance of the Chinese AP1000 plants was closer in line to the original budget estimates. They too were delayed and cost more than projected. While the numbers shown are Chinese costs reflecting lower labor and consumable cost than other countries, the key is the escalation between original and final cost estimates which provide an indicator of the effectiveness of the firms building the plants and schedules.

While China's labor costs are significatly lower than in the US and the regulatory system is different, it has an aggressive regulator that insists on safety standards which are internationally based. Having served for many years on the Nuclear Safety Oversight Board of the Daya Bay and Ningde Nuclear plants, I can testify to the seriousness of nuclear safety of these plants. While the regulator is not as intrusive as the US Nuclear Regulatory Commission, the expectations are equivalent as to safety performance.

[1] This chart comes from the Statistica web site. Normally construction costs are expressed in Kwe or Mwe. It is assumed that they included costs of fuel, operations and maintenance in these numbers to arrive at a cost per Kwe/hr and that the comma, is a period. i.e. 2.2 Euros/kwhr

Taishan, China – 2 units 1,750 MWe European Pressured Water Reactor (EPR)

Start Date: 2009/2010 Initial Operating Date: 2013 Commercial Operation: 2018/201
Initial Project Cost: ? Billion Final Project Cost: $ 7.5 Billion

Taishan became the first EPR to start commercial operation in the world beating out Finland and France due to their difficulties. The reference plant for the Taishan plants is Flamanville whose reference plant was Olkolituo. Over 1,000 lessons learned from both plants was applied to Taishan and despite those, delays and cost overruns occurred suggesting a challenging design to build. EDF has acknowledged severe difficulties in building the EPR design and is working on another version. It should be noted that the Chinese have a regulatory agency that is charged with licensing and overseeing the construction and operation of nuclear plants. The National Nuclear Safety Administration issued permission to load fuel for the first unit in 2018. In 2017, the Taishan company conducted a comprehensive evalutation of the engineering construction plan and associated risks and determined to adjust the construction schedule most likely due to similar problems experienced in Finland and France. The original 46 month construction schedule was lengthened to an actual 88 month construction period. [21,22]

Sanmen, China – 2 Units 1,100 Mwe Westinghouse AP1000

Start Date: 2009/2009 Initial Operating Date: 2013 Commercial Operation: 2018/2018
Initial Project Cost: $ 5 Billion Final Project Cost: $ 7.7 Billion

Sanmen units were built by the State Nuclear Power Technology Corporation, the Sanmen Nuclear Power Company (a special purpose company established to build and operate the plants), with the main civil contractor the China Nuclear Industry Fifth Construction Corporation (CNF). The Shaw group (Westinghouse) has been contracted to provide engineering procurement, commissioning, document control and project management services. Westinghouse submitted the Preliminary Safety Analysis Report to support the issuance of a construction permit in March 2009. [23]

What is unique about the Sanmen project is that both units were built essentially simultaneously with completion of construction within months of each other as was the commericial operating date. The Chinese built the same modular construction fabrication facilitiess that Shaw had built in the US to support their multiple AP 1000 orders. This facility in Haiyang can build structural modules and containment vessel sections for up to 4 plants per year. To our knowledge, they did not have the same manufacturing issues that plagued the Shaw's Lake Charles facility in the US. The schedule performance shows that the Chinese construction companies can apply the the needed amount of labor and obtain components on time. The success of their localizaton effort, in which companies are encouraged to seek Chinese sources of supply, likely contributed to improved schedular performance. Interestingly a key delay item was the main coolant pumps provided by a US vendor that failed performance tests and needed to be redesigned. (These pumps are still causing operating problems).

As with the French EPR design, the Sanmen Westinghouse AP1000 plant was the
first operating plant in the world despite being years behind US plants in starting the project. This obviously shows how different and arguably more effective construction management and regulatory oversight is in China allowing for what one might call more normal and expected construction plans and schedules. Clearly the advantage in China is that it has a large new nuclear build program underway and has experienced construction and fabricating capabilties which have eroded in the west. China has 10 more twin AP1000 projects planned in various locations. Thus, the lessons learned will be applied to these future projects.

Having briefly reviewed the failures and successes of nuclear construction projects, one can now review some of the key findings of the other studies on this topic.

Industry Lessons Learned

Royal Academy of Engineering [13]

"Nuclear Lessons Learned"

Highlighting this excellent report, although prepared prior to the completion of many of these projects, is difficult. There are many meaningful and useful suggestions but only a few will be listed:

- The design must be mature with most regulatory issues resolved with the regulators
- Establish a qualified team of experts experienced in nuclear construction to plan the procurement and build schedule in detail with all collaborative contractors
- Ensure subcontractor are also of high quality and familiar with the stringent nuclear requirements including documentation and quality control.
- New stations should be based on proven technology with a licensing basis that is clearly stated and agreed to by the regulator before commitment to construction
- To the extent possible, the project team should all be co-located at a central facility and on- site
- Three dimensional modeling of the plant done early is an essential tool for constructability
- Schedules must be detailed and actively managed including quality assurance steps
- Modularity should be used to the extent possible to avoid costly site "stick build" designs.
- A strong integrated data base of design, procurement and schedule is needed for contractors
- A risk register documenting high risk evolutions and what precautions are needed.
- Strong government support and commitment is needed to facilitate construction
- While using replicate designs can reduce risk, it is vital to acknowledge that countries may have different requirements and practices including labor contracts.
- Project management requires a development of shared risks to avoid conflicts in the future with a process of resolving disputes without holding back progress on the plant.

Nuclear Energy Institute (USA) [25,26]

"Strategic Project Management Lessons Learned& Best Practices for New Nuclear Power Construction", April 2020.

Although this study is confidential, a publicly available Executive Summary presents the following attributes. Their report was intended to review best practices of plants that have been built in the US in the past decades. The lessons learned are similar. The study reviewed over 100 documents with an extensive reference list which was included in the Appendix. The key findings are listed below: [25]

A. Project Organization, Owner Led Integrated Team, and Best Athlete Approach
   1. Extreme Ownership and Leadership from the Top
   2. Organizational Challenges are Tougher than Technical Issues
   3. Collaborative instead of Confrontational Contracting Strategies
   4. Aggressive Risk and Opportunity Management instead of Risk Shedding Approach
   5. Ingrained Large Nuclear Construction, Quality, and Safety Culture and Mentality

B. First of a Kind (FOAK) Project Parameters and Challenges
   1. Recognizing what FOAK Is
   2. Experience of Stakeholders
   3. Design Maturity and Details Required for Construction
   4. Realistic Cost and Schedule Baselines

C. Project Management Involves Art and Science
   1. Integrated Project Schedule, Owner Control, and Simplified Reporting System
   2. Rigorous Configuration Management and Design Change Control
   3. Labor Efficiency, Extended Workweeks, Shift work, and Fatigue
   4. Modularization Potential Benefits and Drawbacks
   5. Managing Project Internal and External Stakeholders

Extreme ownership and leadership was judged to be the most important criteria by the authors of this report for successful execution of past projects.

The Meridian Services Group, who worked on this study, also examined other factors affecting projects that succeed and fail as it affects leadership behavior and why lessons learned are not heeded. They call these "blind spots" and obstacles to implementing lessons learned. Blind spots are frequently defined as "hubris" or arrogance due to excessive pride and dangerous over confidence. They involve planning and knowledge management – i.e. dealing with information. [26]

- Inadequate experience in first of a kind projects in the nuclear industry or country
- Conservative corporate cultures that clash with aggressive project mindsets
- Human emotions, personalities and leadership which is an amazing effect when it works well and destructive when poorly managed. (selection)
- The conflict between long term strategic vs. short term considerations.

- Leadership belief that they are the smartest people in the room and the lessons learned don't apply to them.

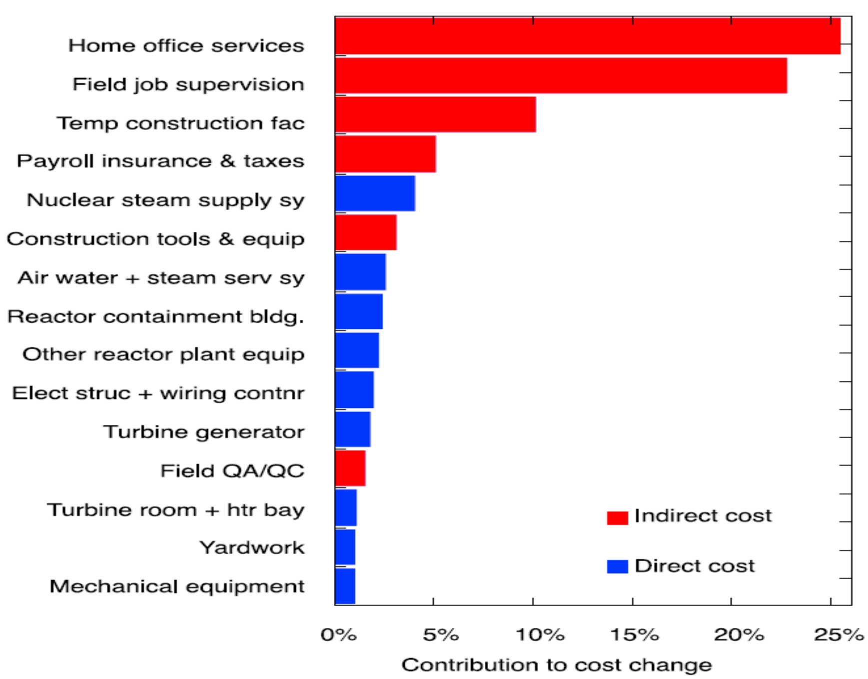
Massachusetts Institute of Technology [27]

"Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design"

In 2020 MIT Nuclear Science and Engineering published a study [27] to better understand the reason for nuclear cost increases over 5 decades and based on their studies, they reached a counter intuitive conclusion for this period. Namely, that the nth of a kind reactor cost more than the first of a kind. This may be a unique finding due to the time of rapid nuclear expansion in the US with evolving and changing regulations due to the Three Mile Island accident and a lack of standardization such that nth of a kind really did not mean much since so many changes in reactor design were mandated.

They did have an interesting finding that appears applicable today in that so called "soft" factors contributed to over half of the cost rise during this period. These soft costs covered things such as indirect costs associated with increasing home office engineering costs, supervision, temporary construction, labor costs as opposed to increases in direct charges for components and equipment. This is shown graphically on Figure 2 below: [27]

Figure 2
Nuclear Construction Cost Change

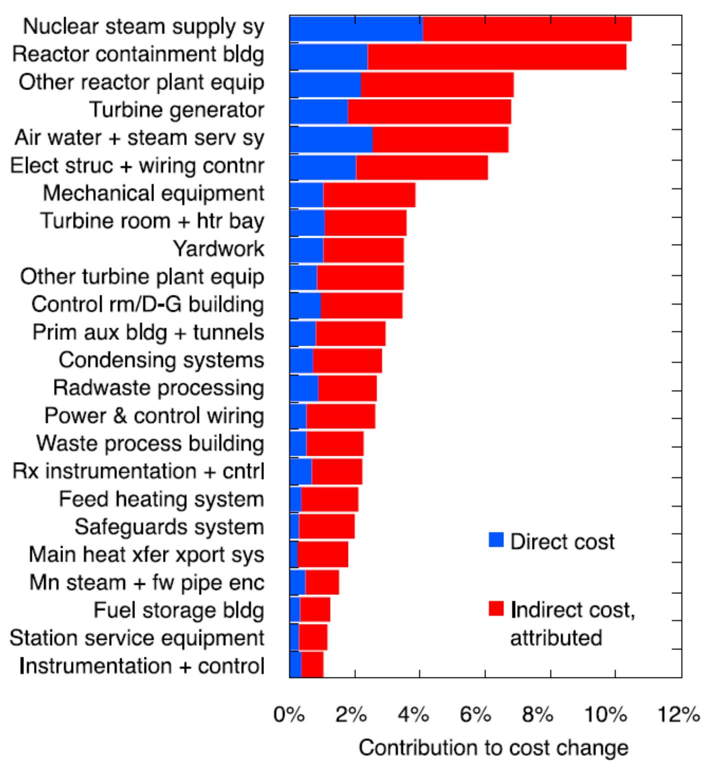


One might conclude these increases were due to increasing regulatory requirements and/or just poor quality of goods purchased and poor labor productivity due to rework and inspections. An area they found was particularly costly was the containment design and the sheer magnitude of making the concrete pours both in the foundation and containment in accordance with design specifications. In addressing some of the cost increases for the same basic 4 loop Westinghouse design, they suggested a proliferation of safety regulations, new codes and standards, rework caused by interferences and design changes needed to comply to the new requirements. They also found that prior to start of construction in the traditional two part licensing process, the detailed design was not complete. They also cite stringent quality assurance requirements and NRC inspections.

The MIT study was exhaustive in terms of trying to allocate costs to these variables to create a model for scenarios to assess where improvements could be made. The chart on Figure 3 below gives one an indication of where to focus to reduce costs since indirect or soft costs largely drive the cost increases. [27]

Figure 3

Contribution to Cost Change by System



The team concluded that since the cost estimating models were diverging from real cost data as the plants were being built, new cost estimating models are needed to factor in productivity of the work force and changes in the regulatory environment.

Electric Power Research Institute (EPRI) [28]

"Advanced Nuclear Technology: Economic-Based Research and Development Roadmap for Nuclear Plant Construction"

EPRI conducted a study of the reasons for cost increases in nuclear plant construction identifying key drivers in higher costs. They were not particularly interested in the costs of delay but the general trend of increasing costs which should be the focus of new construction projects. Not surprisingly, the duration of the construction project was found to be most significant due to the cost of financing and labor charges. The duration was most influenced by civil and structural design and work on containments and other structures. Since the 9/11 attacks in the US, containment design was strengthened requiring more rebar and concrete to withstand jet plane strikes. The cost of materials, at that time, was not viewed as a significant cost driver but in the current time of high inflation worldwide, it surely is now. It should be no surprise that due to the lack of a completed design, the lack of constructability was viewed as a major factor in increasing costs due to redesign and rework also adding to the indirect costs identified in the MIT report discussed earlier. The nuclear island, which makes nuclear unique from other power generating projects, was found to be only 20% of the direct costs. While labor costs was the largest cost driver and inspection delays contributed to reduced worker productivity.

In breaking down the various cost contributors, EPRI found that overnight costs could be reduced significantly by:

Civil and Structural Design	$ 456/kwe
Materials (50% Reduction)	$ 343/kwe (not likely today)
Lack of Constructability	$ 2,338/kwe
Total Possible Reduction	$ 3,421/kwe

Using their baseline overnight capital cost of $ 5,500/kwe, their projected cost could be $ 3421/kwe if all the savings were possible. While these numbers can be challenged, they do providing indicators of where to look in terms of cost savings.

Clearly, the biggest cost driver is the lack of constructability, which is due to not having a detailed design verified by 3-D modeling of the plant creating a "digital twin". While regulatory changes created some of these problems requiring redesign and rework, the additional training for craft dealing with safety grade equipment, intrepretation of regulatory requirement, detailed procedures and documentation requirements for nuclear plants drives the much higher costs.

Summary and Conclusions

Clearly the building of a nuclear plant is a "mega" project" involving thousands of people in many countries that make up the entire supply chain from engineering, detailed design, suppliers, contractors, and ultimately operators and maintenance people. The recent record has not be good for many who see nuclear energy as a vital part of our energy mix. Many lessons learned have been documented yet mistakes continue to be made under pressure to get the project started and construction completed.

Some key personal take aways stemming from NNP stakeholders not recognizing they are planning a FOAK Mega Project that is vastly different from other industry Mega Projects include:

1. Poor reactor technology choice
2. Incomplete detailed design suitable for construction
3. Not recognizing local and national construction standards
4. Inadequate supply chain for nuclear certified parts
5. Lack of nuclear quality culture and poor selection of sub-contractors
6. Poor project management of multiple contractors and oversight
7. Dysfunctional project organizations and poor communications
8. Poor schedule and budget controls based on unrealistic and over-optimistic plans
9. Poor documentation and records/configuration management not meeting requirements
10. No risk management strategy or risk register to track potential problems
11. Failing to recognize and correct problems early.
12. A regulatory system that is not flexible
13. Inadequate qualified work force
14. Local vocal opposition
15. Litigation

When you break these down further you will find that you additionally need a strong cohesive management team of experienced professionals who are aligned for a common purpose and committed to a goal of bringing a project in on time and budget. To do this, it is vital to have a complete design using a three dimensional digital twin of the plant showing all interferences and potential problems in scheduling. The detailing planning is essential for effective project execution. The regulator should be part of the solution, not the problem. Cooperative and constructive trusting relationships based on sound engineering are essential to move forward as problems develop as they typically will. The UAE model is one that should be studied and replicated for first time nuclear plant countries. They seem to have found an approach that works from a technical and regulatory perspective.

Much of the discussion has focused on overnight costs of construction of the plant. Not to be ignored are the commissioning costs, operating and maintenance costs, and fuel that all contribute to the cost of power. Fortunately, most of the cost of power comes from the capital investment in construction (over 70 %). A strong factor in the cost of construction is how long it takes and the cost of financing which in some countries can be several factors higher than in the US. Obviously, the longer the plants take to build with incumbent delays, the higher the cost for the money borrowed or invested.

This all can be summarized by the word "selection". As a young engineer working for Yankee Atomic Electric Company, an old timer who built one of the first commercial Westinghouse 4 loop plants in 4 years, when asked what was the key to success. He said "selection" – selection of the technology and

selection of the people to build and run the plant. Truer words were never spoken
when it applies to today's FOAK nuclear challenge. This personal lesson learned underscores that FOAK organizations present greater challenges than FOAK technical issues….creating effective global teams is easier said than done.

What Should Poland Do?

As I understand it, Poland has decided to move forward with the Westinghouse AP 1000 design.A consortium made up of Westinghouse and Bechtel signed the agreement with the Polish state-owned utility overseeing the nuclear program, Polskie Elektrownie Jądrowe (PEJ).Thus, the selection has already been made. Hopefully the selection process was thorough considering all the criteria and lessons learned discussed above.

This decision is likely based on the fact that at least six AP 1000's are now operating in the world and that the Westinghouse team has really learned those tough lessons about the design and how to build it efficiently. One might also need to assume that the price and financial package was such that it was a competitive long term investment which benefited consumers in Poland and Europe.

Now comes the hard part. Having selected the technology, one must select the people to build and operate this plant. While both companies have good reputations despite the difficulties at Vogtle, the keys are the people who will be assigned to manage the project and contractors hired (many locally) that have the necessary skills and safety culture needed for nuclear grade work. Getting these people qualified will be a challenge. As the UAE found, operational readiness was not completed when the plant's construction was finished. The owner utility should assure that Westinghouse and Bechtel understand the local and European Commission regulations relative to construction standards as the Olkolituo experience has shown. Hopefully, the Westinghouse and Bechtel team have some kind of investment stake in the plant for long term common interest.

It also must be recognized that Westinghouse and Bechtel are private companies and are not part of a national government owned/controlled economy like China, Japan, and South Korea. Private companies are more driven by short-term profitability and must meet corporate shareholder expectations. Nationalized companies like KEPCO are more interested in long-term services through the 80-year nuclear plant life cycle and can better withstand variances from planned construction costs.

Establishing a new regulatory system capable of reviewing and workingwith the contractors to handle discrepanciies as they appear will be vital to maintaining a decent schedule. While the 2033 date for commercial operation is aggressive,having a completed detailed design and execution plan will reduce project risks. Establishing a Quality Assurance program for design, construction and vendors in the supply chain should be a priority.

Independent oversight of the project is highly recommended by qualified personnel to determine whether the engineering design meets local and national standards. This team should have continual presence at the critical offices on the project and on-site to oversee progress. Special quarterly reviews should be held with other outside experts (such as a Senior Oversight Board) to question the oversight process and

report to the owners to identify problems early and monitor corrective actions.
The role of Quality Assurance inspections of the entire supply chain and onsite construction is vital to catch these problems early to avoid costly rework and delays. The document control system should be thorough and but not be designed to be overly burdensome. Given that there is already opposition from German authorities, it will be important to have a strong community outreach program to avoid demonstrations that will impede work and possibly litigation.

There have been successful projects that have experienced good performance in Korea, the United Arab Emirates and China. While these lessons have been well understood, for some reason they have not been learned likely because once a project fails to meet cost and schedule goals, no utilities will consider taking on the risk of trying again such as in the US. We hope that Poland will carefully study the lessons and prepare for the execution of their project with those in mind.

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