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Characterization of Potential Construction Schedules for Advanced Reactors

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July 2021

OAK RIDGE
National Laboratory

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Nuclear Energy and Fuel Cycle Division

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ABSTRACT

Advanced reactor designs differ from the traditional light-water reactor designs and operational requirements in nearly every facet, including the heat transfer fluids, operating temperatures and pressures, and fuel cycle requirements. To account for these differences, significant effort will be required to ensure appropriate safeguards implementation for US-based reactors intended for global deployment. This paper is the first in a series of three that examine facets of this issue. It examines potential construction schedules for advanced reactors to create a baseline understanding of the timeframes involved. The second paper (ORNL/TM-2021/2202) characterizes International Atomic Energy Agency (IAEA) safeguards implementation schedules for potential advanced reactors. Finally, the third paper (ORNL/TM-2021/2208) will examine gaps that exist for safeguards implementation at advanced reactors.

Modern construction methods and techniques have advanced beyond those used to build the majority of the existing global fleet of power reactors. Furthermore, economic pressures will push power reactor construction to the minimum possible schedule time and expedite the approach to operation, which will minimize the amount of time available during construction to install and verify safeguards infrastructure. The combination of the needed technological maturation and schedule pressure means that the international community will have a relatively short window for effective safeguards implementation before initial operation. This report provides a characterization of the most likely scenarios for accelerated deployment of advanced reactor technologies, which will provide the most challenging timelines for safeguards program design, development, and installation before reactor operation.

Broad characterization of advanced reactor construction schedules must be performed to begin planning for safeguards implementation. Although an accurate and detailed schedule is not yet possible for the US-based advanced reactors, reasonable approximations can be made based on the historical information of as-built US-based reactors and international analogs. Overall, the estimated fastest time from site selection to operation is just under two years. This assumes that site preparation and construction occur in parallel with reactor module factory fabrication, with just-in-time delivery of the module(s) to the construction site. Site selection, licensing, and regulatory schedules are excluded from this paper due to a high level of variation between nations and regulatory systems; only physical construction timelines are addressed.

1. INTRODUCTION

Advanced reactor (AR) designs include the gas-cooled reactor (GCR), molten salt reactor (MSR), and small modular (micro) reactor (SMR micro reactor). These designs deviate from the traditional light-water reactor (LWR) design and operational requirements, which will lead to departures from traditional construction pacing, requirements, and supply chains. Simplifications in design and advanced construction methods will reduce the time to deployment; this shortened construction period also shortens the amount of time available to design, implement, and begin operations for safeguards equipment, activities, and personnel. In general, advanced and microreactor design and construction efforts will be focused on decreasing construction cost, time, and effort, which will impact the safeguards implementation schedules.

This report provides a characterization of most likely scenarios for accelerated deployment of AR technologies developed by US vendors. In turn, these scenarios will provide the most challenging timelines for international safeguards program design, development, and installation before reactor operation.

2. BACKGROUND

2.1 PROJECT PURPOSE

This report provides a broad characterization of the potential construction schedules for ARs, for the purpose of understanding available time for international safeguards implementation. The International Atomic Energy Agency (IAEA) is the organization responsible for oversight of international safeguards deployment. Because there is a diverse array of advanced reactor types with varying physical characteristics, any proposed construction schedules are approximations to be used only to plan potential safeguards deployment schedules. All statistical analyses were performed and plotted using MATLAB®.

2.2 ADVANCED REACTOR INFORMATION SYSTEM

To develop a set of publicly available background and reference data suitable for analysis, all advanced reactor information was taken from the Advanced Reactor Information System (ARIS), which is maintained by the IAEA. Per the IAEA,

> "The Advanced Reactor Information System (ARIS) is a database designed and maintained by the IAEA's Nuclear Power Technology Development Section (NPTDS) since 2009. The most important content of ARIS are the design descriptions of evolutionary and innovative advanced nuclear reactors. ARIS enables users to easily get an overview of the current reactor technologies being developed and deployed by giving people access to the designers' design descriptions" [1].

The primary caveat (discussed in a following section) is that ARIS includes reactors in various stages of design maturity, which means that it includes a mix of historic information and projections.

2.2.1 ARIS Overview

At this writing, there are 78 ARs listed in ARIS [1]. Each of these reactors has a status report submitted by the designer. Of the 78 designs, 42 contain an estimate for the construction time from first concrete pour to criticality. These data are summarized in Table 1 and represented in Figure 1 as a box-and-whisker plot. This type of plot graphically conveys the 25% (i.e., Q1), 50% (i.e., Q2), and 75% (i.e., Q3) quartiles (indicated by solid red and blue lines), 0% and 100% quartiles (shown as solid black lines), and any outliers (depicted as red "+" markers). A box-and-whisker plot allows for interpretation of the spread of data being analyzed, emphasizing the quartiles and outliers.

Table 1. Descriptive statistics for ARs listed in the IAEA's ARIS database [1]

Statistic	Value
Count	42
Mean	44.9 months
Median	39 months
Mode	36 months
Range	102 months
Minimum	18 months
Maximum	120 months
Q1	36 months
Q3	54 months
Upper adjacent	72 months
Lower adjacent	18 months
Outlier(s)	1 (120 months)
Standard Deviation	18.76
Kurtosis	4.956
Skewness	1.6567

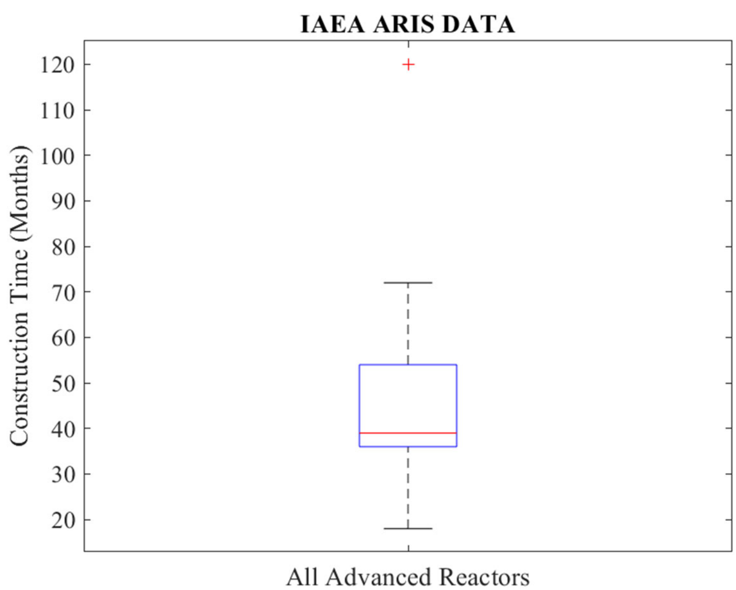

Figure 1. Box-and-whisker plot for ARs listed in the IAEA's ARIS database [1].

The data suggest that—from a nonproliferation and safeguards implementation perspective—the worst-case scenario would be 18 months from concrete to criticality. Furthermore, the skewness indicates that there are more designs with construction times on the lower end of the spectrum than the higher end. This is also seen in the median duration (39 months) being less than the mean (44.9 months). The standard deviation of approximately 19 months, or around half the median, suggests that the construction times vary greatly from the mean. The kurtosis is greater than 3 because of the presence of the extreme outlier of 120 months. Thus, as an approximation, the anticipated range of construction time could be estimated as 36 months ±18 months.

2.2.2 ARIS by Design Status

Each status report contains a categorization of the design status for the advanced reactor. In order of increasing maturity, the categories are the following: conceptual design, basic design, detailed design, under regulatory review, licensed, construction, and in operation.

Conceptual designs are typically ideas for reactors, including proposed coolants, moderators, and power outputs. Basic designs are more fleshed out than conceptual designs and usually contain diagrams/schematics. Detailed designs are the most developed designs that have yet to begin the review or licensing process, and these designs have undergone some level of optimization and simulation.

Table 2. Descriptive statistics for ARs, categorized by design status [1]

Statistic	Conceptual designs	Basic designs	Detailed designs	Designs under construction	Designs in operation
Count	20	5	6	6	3
Mean	43.7 months	46.9 months	41.7 months	50.3 months	51 months
Median	36 months	54 months	42 months	52 months	48 months
Mode	36 months	n/a	n/a	54 months	48 months
Range	96 months	30.5 months	54 months	24 months	9 months
Minimum	24 months	29.5 months	18 months	36 months	48 months
Maximum	120 months	60 months	72 months	60 months	57 months
Q1	29 months	36 months	27 months	49 months	48 months
Q3	48 months	55 months	18 months	54 months	54 months
Upper adjacent	72 months	60 months	72 months	60 months	57 months
Lower adjacent	24 months	29.5 months	18 months	48 months	48 months
Outlier(s)	1 (120 months)	n/a	n/a	1 (36 months)	n/a
Standard deviation	23.85	13.3	19.9	8.1	5.2
Kurtosis	4.63	–2.35	–0.52	1.93	n/a
Skewness	2.022	–0.605	0.395	–1.088	1.732

There are 31 conceptual designs in the database, and 20 include an estimate for construction times from concrete to criticality. Furthermore, there are 24 basic designs listed in the database, but only 5 of these entries have an estimate for construction times from concrete to criticality. Additionally, there are 6 detailed designs in the database, each of which has an estimate for construction time from concrete to criticality. There is 1 design under regulatory review, and the construction time estimate is 36 months. Additionally, there are 2 licensed designs in the database, but only 1 lists an estimate for construction time (36 months). There are 8 designs under construction in the database. 6 of these have an estimate for construction time from concrete to criticality. Lastly, there are 6 designs in operation in the database, 3 of which have an estimate for construction time from concrete to criticality. A summary of these data and a graphical representation can be seen in Table 2**Error! Reference source not found.** and Figure 2, respectively.

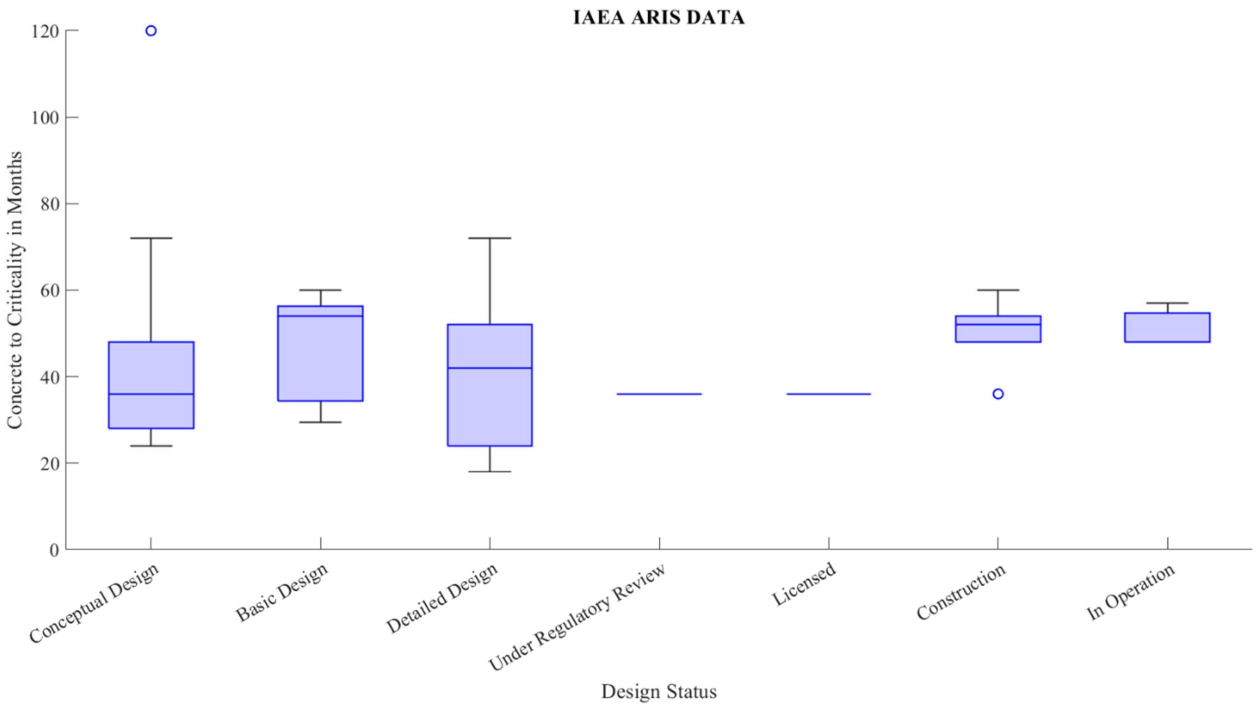

Figure 2. Box-and-whisker plot for ARs, categorized by design status [1].

As anticipated, there are many more ARs in the three design phases than ARs being reviewed, licensed, constructed, and in operation. Particularly, conceptual designs are far more abundant than any other category. Moreover, the minimum and mean construction times for the reactors in any of the three design phases are less than those of reactors further into the development process. This suggests a few possibilities: designers' optimism about construction time exceeds that which can feasibly be achieved; the designs with quicker construction times are not yet viable in an engineering sense; or the designs with quicker construction times are not yet viable in an economic sense. Global experience suggests that the first option—the designers are overly optimistic—is most likely.

2.2.3 ARIS by Reactor Type

Each status report contains a categorization of the type of advanced reactor. The categories are boiling water reactor (BWR), gas-cooled reactor (GCR), gas-cooled fast reactor (GFR), heavy-water reactor (HWR), lead-cooled fast reactor (LFR), molten salt reactor (MSR), pressurized water reactor (PWR), sodium-cooled fast reactor (SFR), integral pressurized water reactor (iPWR), supercritical water-cooled reactor (SCWR), and small modular (micro) reactor (SMR micro). The counts for each type of reactor are shown in Table 3.

Table 3. Counts of each advanced reactor type in the ARIS database [1]

Reactor type	Count (in database)	Count (with construction times)
BWR	6	4
GCR	5	3
GFR	3	1
HWR	5	2
LFR	12	6
MSR	8	3
PWR	22	17
SFR	10	4
iPWR	3	2
SCWR	3	0
SMR (micro)	1	0

The reactor with the fastest construction time (18 months) is in the PWR category. The category with the fastest mean construction time is MSR (28 months). As shown in Figure 3, the categories have significant overlap, and most have wide ranges. Thus, based on these data, it is neither possible nor advisable to establish a relationship between construction time and type of advanced reactor.

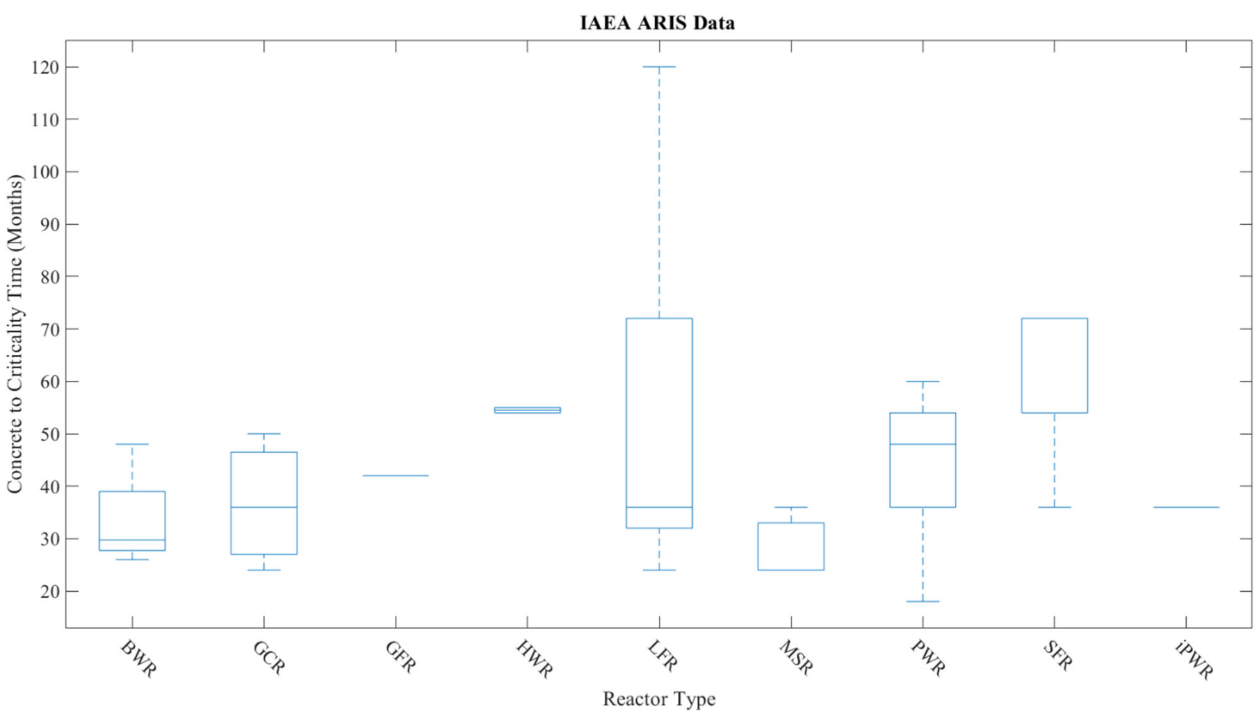

Figure 3. Box-and-whisker plot for ARs, categorized by reactor type [1].

Similar results were found when examining construction times for the different moderator and coolant types, as shown in Figure 4 and Figure 5, respectively. The fastest construction time (18 months) uses light water as the coolant and moderator, and the moderator category with the fastest average construction time is graphite. Again, the construction times for the categories overlap enough such that a relationship cannot be established between moderator/coolant and construction time.

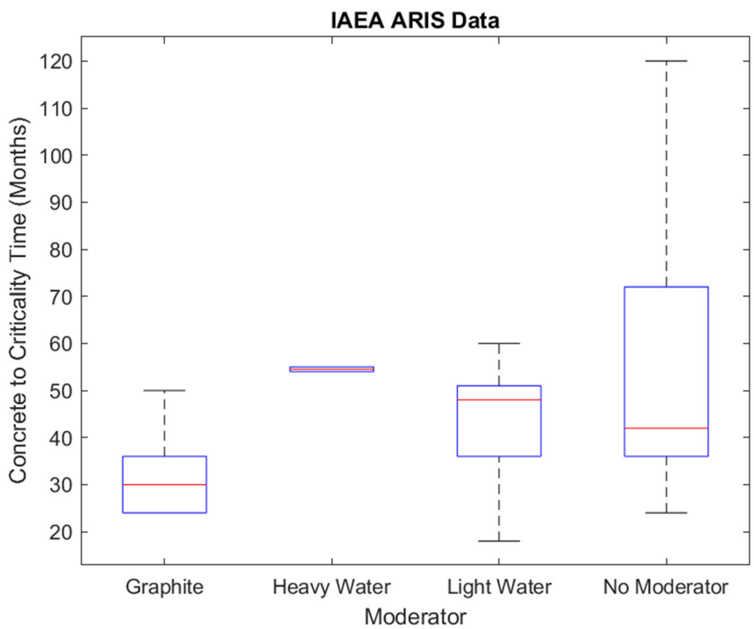

Figure 4. Box-and-whisker plot for ARs, categorized by moderator type.

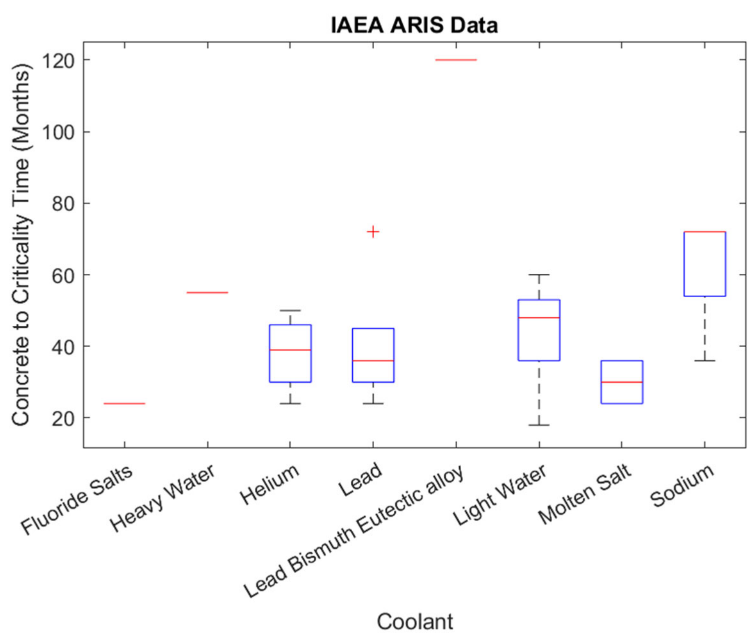

Figure 5. Box-and-whisker plot for ARs, categorized by coolant type.

2.2.4 ARIS by Geographical Location

Each status report categorizes the advanced reactor by the country of its designing organization. Note that EU refers to the European Union as a disjoint category from member nations.

Table 4. Number of advanced reactor type categorized by country [1]

Country	Count (in database)	Count (with construction time)
Belgium	1	0
Brazil	1	0
Canada	3	3
China	5	4
Denmark	1	1
EU	4	1
France	6	3
India	4	0
Japan	11	3
Luxembourg	1	1
Rep. of Korea	7	5
Russia	13	8
South Africa	1	1
Sweden	2	2
UK	1	1
USA	17	9

Figure 6 is a visualization of the data shown in Table 4, categorized by country. China has both the fastest (18 months) and slowest (120 months) concrete to criticality time for an advanced reactor. The minimum estimate for an advanced reactor from the USA is 24 months, and the median time estimate for the USA is 36 months.

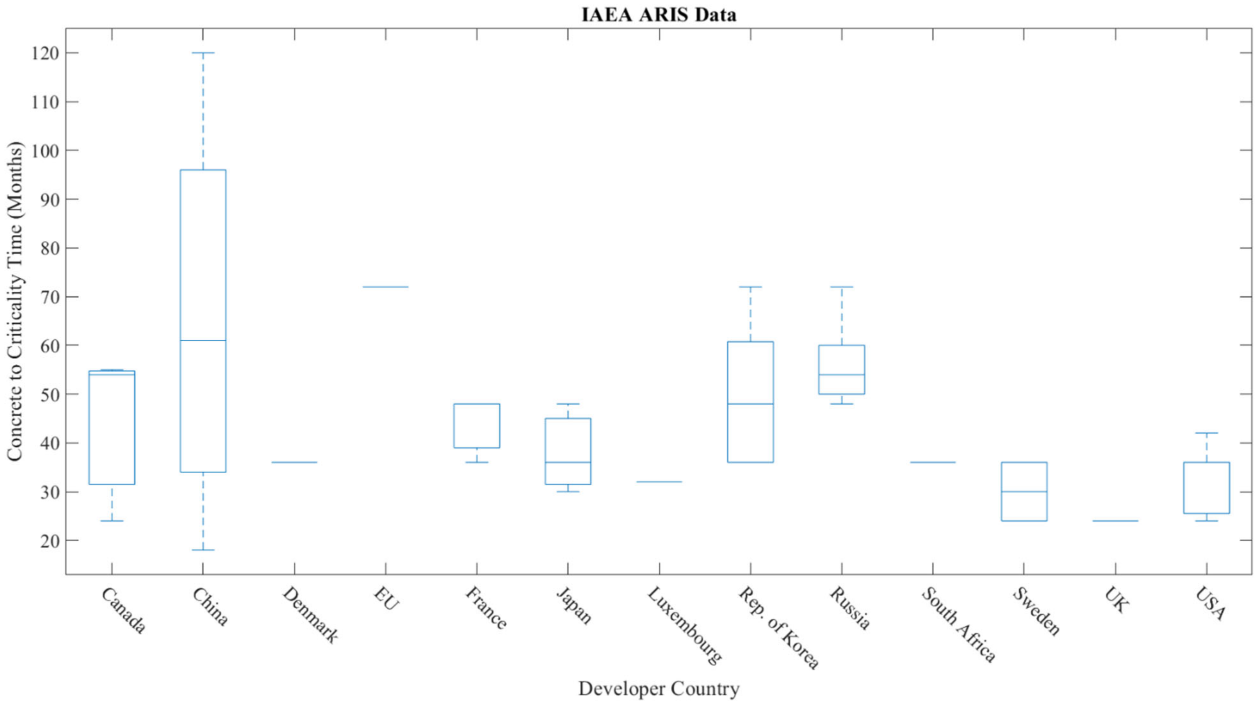

Figure 6. Box-and-whisker plot for ARs, categorized by geographical location [1].

2.2.5 ARIS by Power Output

The 42 ARs in the database with construction times also list specified power outputs. The power outputs range from 0.2 MWe to 1770 MWe. As shown in Figure 7, there is almost no correlation between estimated concrete to criticality time in months and power output in MWe. A correlation value of 0.01 was found, which confirms the visual observation.

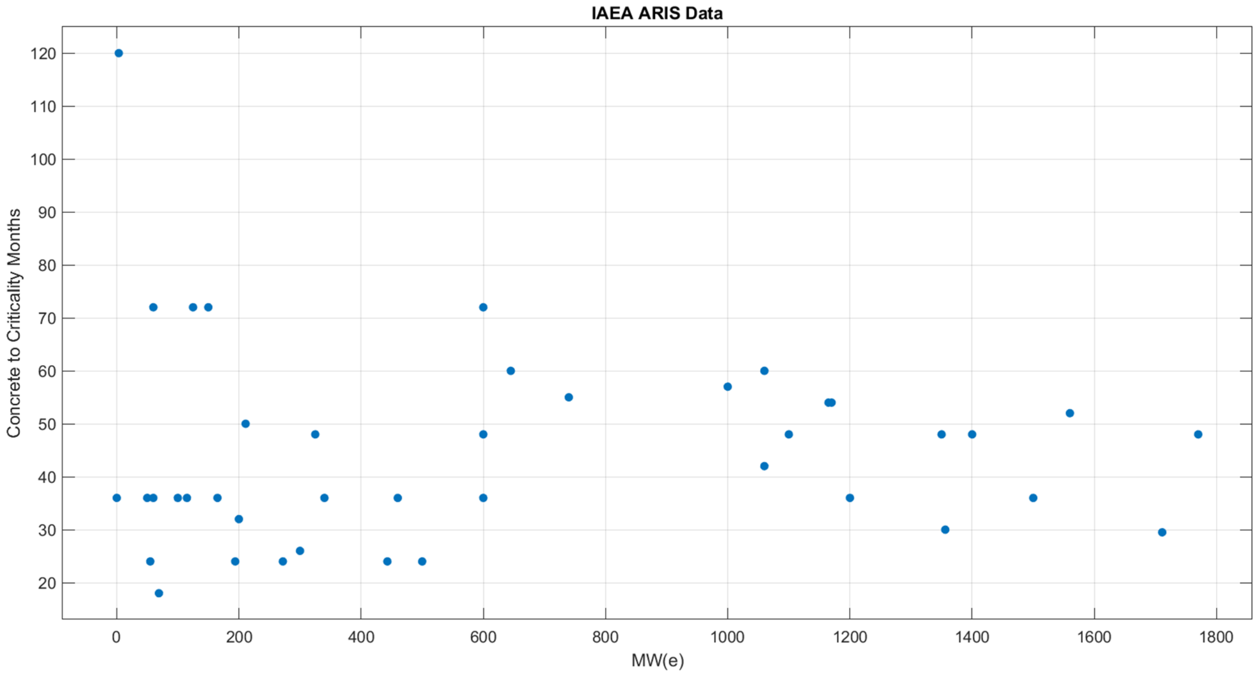

Figure 7. Scatter plot of ARs comparing power output to construction time [1].

2.2.6 ARIS by Reactor Generation

Nuclear reactors span multiple generations. ARs fall into three generations: Generation III, III+, and IV. The generations have standard definitions. Generation III ARs are evolutionary or improved versions of existing Generation II designs achieved via modifications. Likewise, Generation III+ reactors are an evolutionary development from Generation III designs. Generation IV, however, consists of reactors the designs of which are innovative or incorporate major changes. Advanced PWRs, BWRs, and HWRs fall into the Generation III and Generation III+ categories. Conversely, SCWRs, GCRs, SFRs, MSRs, GFRs, and LFRs are considered Generation IV reactors.

Of the 42 designs in the ARIS database with estimated construction times, 11 are Generation III, 14 are Generation III+, and 17 are Generation IV.

Figure 8 provides a visualization of the data, organized by generation. The fastest concrete to criticality time estimate (18 months) is a Generation III+ reactor. The slowest concrete to criticality time estimate (120 months) is a Generation IV reactor.

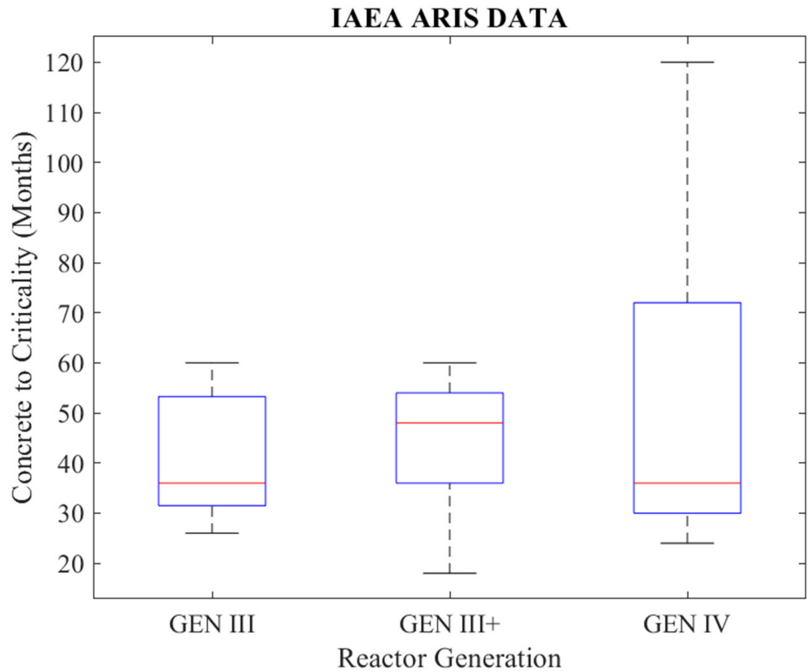

Figure 8. Box-and-whisker plot for ARs, categorized by reactor generation [1].

On average, the generation III reactors (mean = 42, median = 36, mode = 36 months) reactors have lower construction time estimates than Generation III+ reactors (mean = 44, median = 48, mode = 48 months) and Generation IV reactors (mean = 48, median = 36, mode = 36 months). Generation IV reactor construction time estimates have a far greater range, standard deviation, and skewness (96 months, 26 months, and 1.52, respectively) than the Generation III (34 months, 12 months, and 0.25, respectively) and Generation III+ (42 months, 12 months, and 0.94, respectively). This variance is likely a product of the innovation and variety in Generation IV designs compared to Generation III and Generation III+ designs. Additionally, the large spread with respect to the Generation IV reactor designs implies an inherent uncertainty in the path to construction and deployment for these types of reactors.

2.3 RESEARCH REACTOR DATABASE

A second source of reactor information is the IAEA's Research Reactor Database (RRDB), which stores information on the world's research reactors. Given that some of the research reactors around the world could be considered ARs or have power levels on the order of some of the proposed ARs for power production, these data are informative for this report as well. Per the IAEA, "The IAEA's Research Reactor Database (RRDB) is an authoritative database containing technical information on over 800 research reactors, including critical and sub-critical assemblies in 67 countries" [2].

2.3.1 RRDB Overview

There are 746 research reactors in the RRDB that have completed construction [2]. Of these entries, 571 include construction dates; 30 have reported construction times of 0 days and were excluded from the analysis. The following analysis is based on the 541 research reactors in the RRDB that have different construction start dates and criticality dates. Table 5 summarizes the descriptive statistics for this dataset. Furthermore, Figure 9 and Figure 10 depict these data graphically as a box-and-whisker plot and a frequency histogram, respectively.

Table 5. Descriptive statistics for research reactors listed in the IAEA's RRDB [2]

Statistic	Value
Count	541
Mean	31.6 months
Median	24 months
Mode	12 months
Range	451 months
Minimum	0 months (17 days)
Maximum	451 months
Q1	12 months
Q3	41 months
Upper Adjacent	84 months
Lower Adjacent	0 months
Outlier(s)	30 (87–451 months)
Standard Deviation	32.86
Kurtosis	50.972
Skewness	5.0255

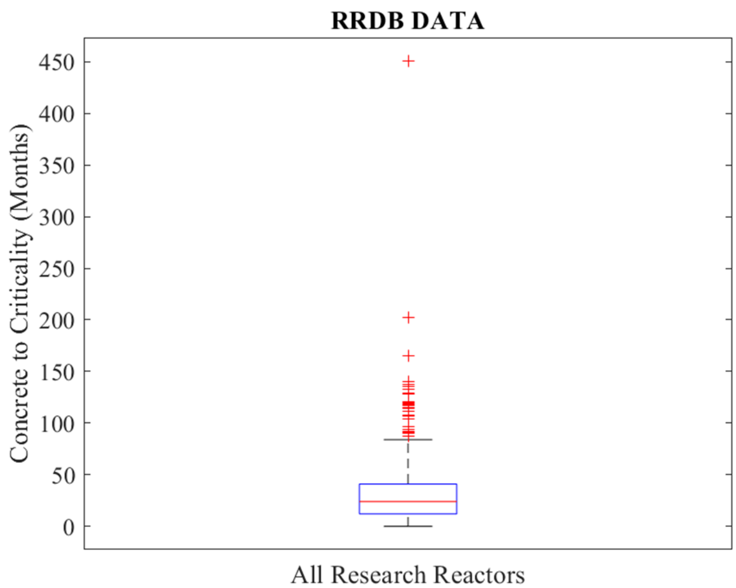

Figure 9. Box-and-whisker plot for research reactors listed in the IAEA's RRDB [2].

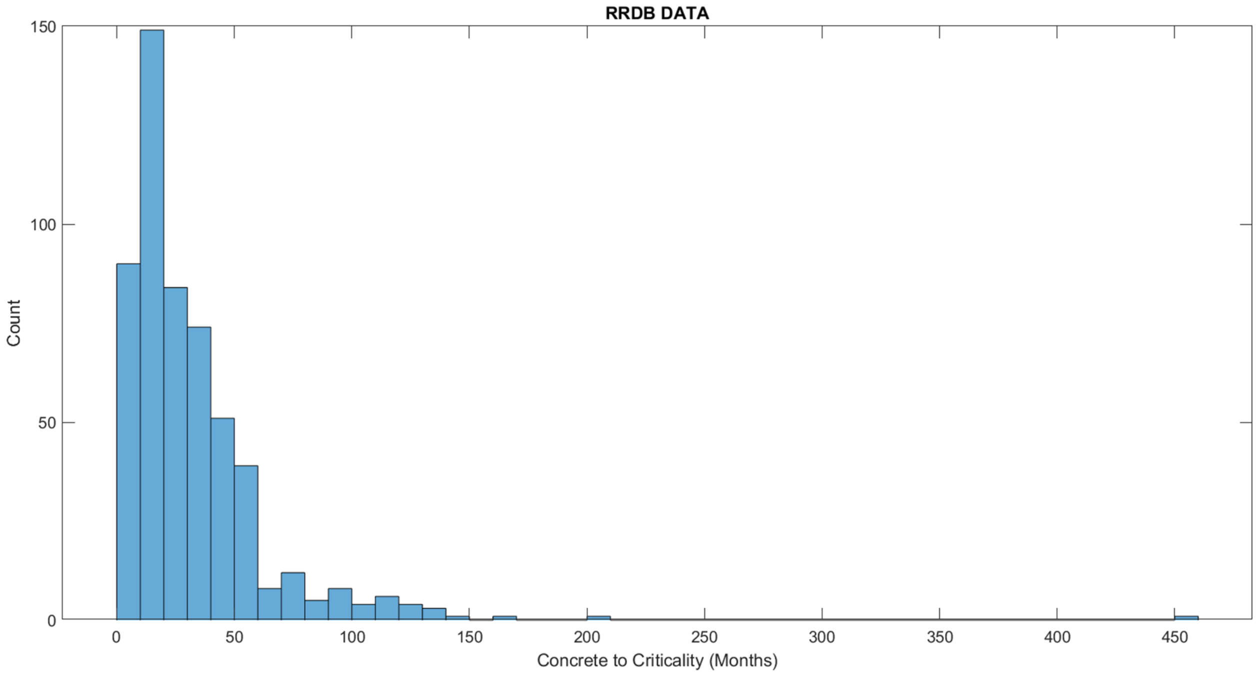

Figure 10. Histogram of construction time of research reactors listed in the IAEA's RRDB [2].

The skewness indicates there are more research reactors completed on the lower end of the time spectrum than on the higher end. This is also demonstrated by the median (24 months) being less than the mean (31.6 months). The high standard deviation of 33 months—greater than the mean of 32 months—suggests that the construction times vary greatly from the mean. The very high kurtosis (50.972) is because of the presence of the 30 outliers.

2.3.2 RRDB Data by Decade

As shown in Figure 11, the number of research reactors breaking ground peaked from the late 1950s to the late 1970s. This may cause concern that the data are skewed by the construction times during that period. However, as evidenced by Figure 12, the construction times do not vary significantly from decade to decade.

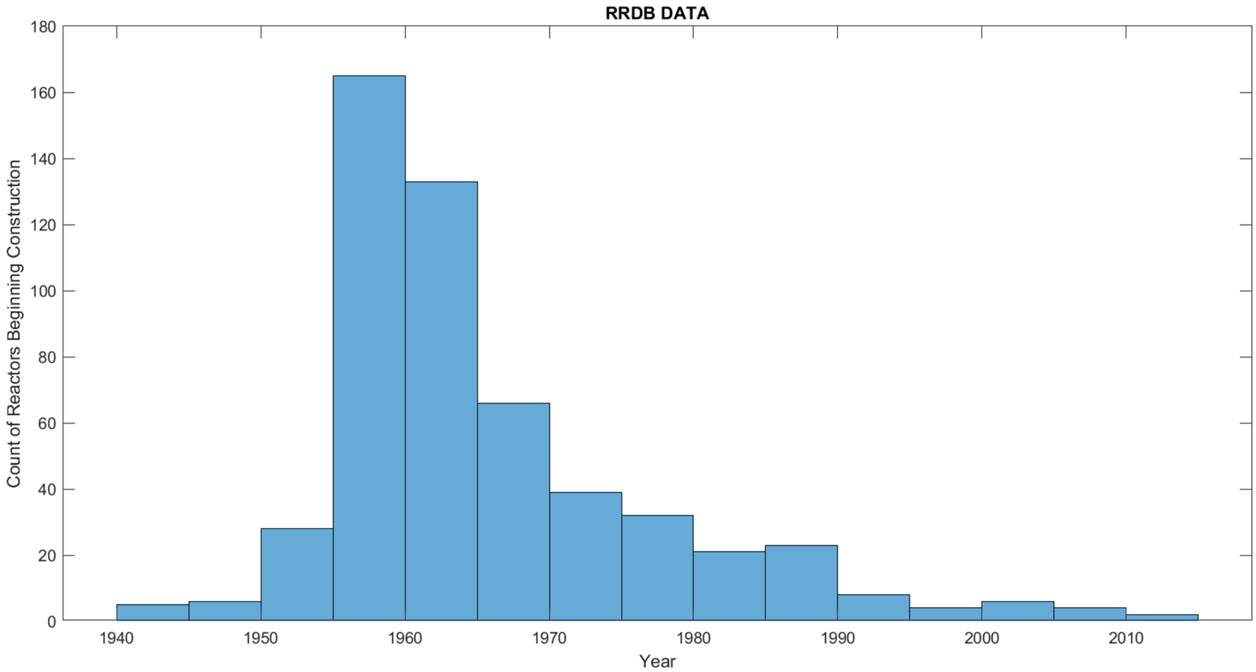

Figure 11. Histogram of construction start dates of research reactors [2].

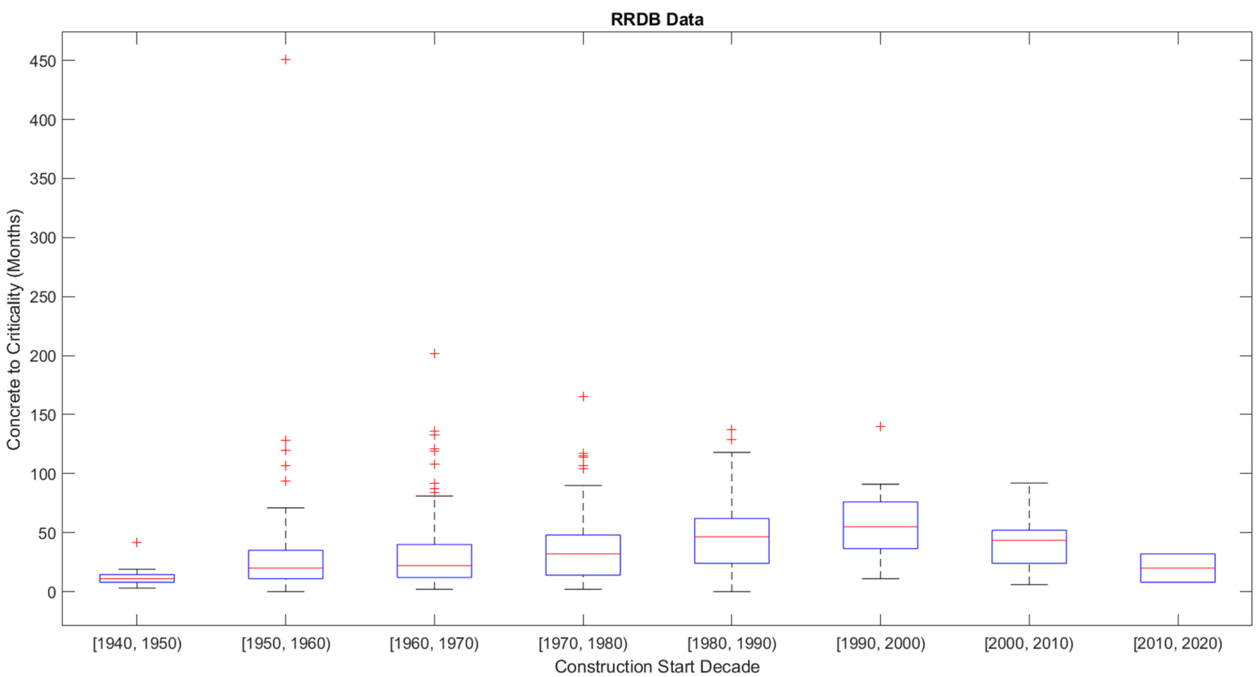

Figure 12. Box-and-whisker plot for research reactors, categorized by construction start date [2].

2.3.3 RRDB Data by Power

As seen in Figure 13, most research reactors produce less than 1 MWt. Only a single advanced reactor from the ARIS database is designed to produce less than 1 MWt. Therefore, it is valuable to examine the research reactor data in the bins shown in Figure 14, focusing on the bins in which the power output is 1 MWt or greater.

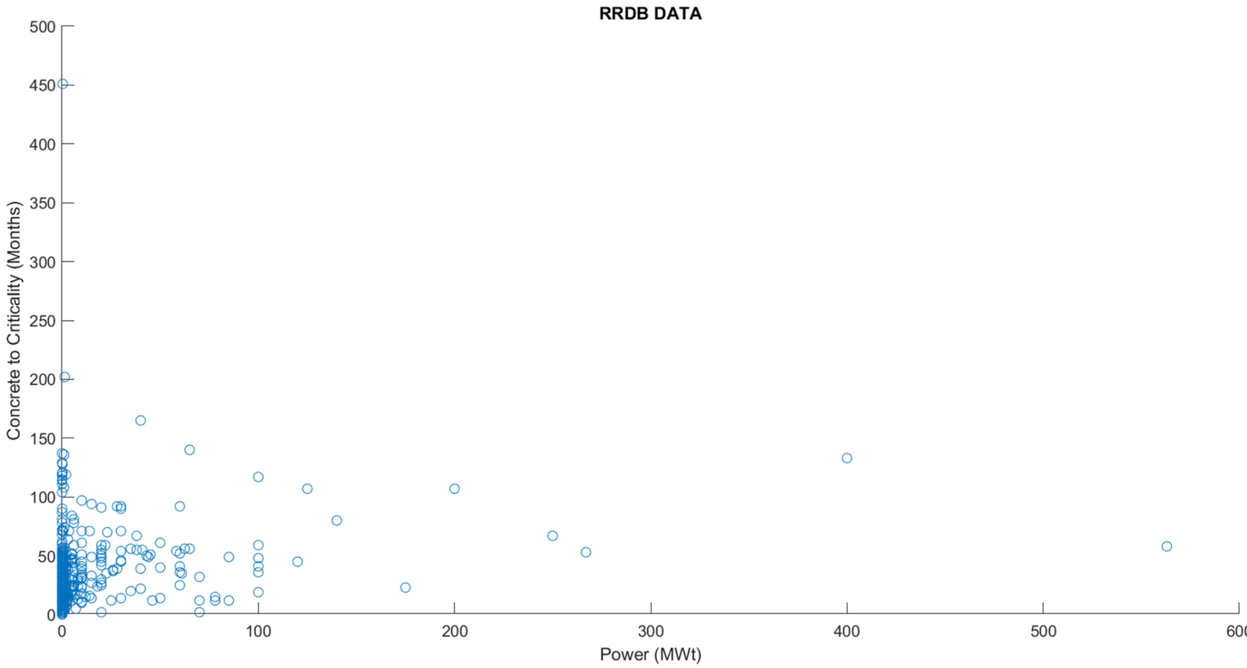

Figure 13. Scatter plot of research reactors comparing power output to construction time [2].

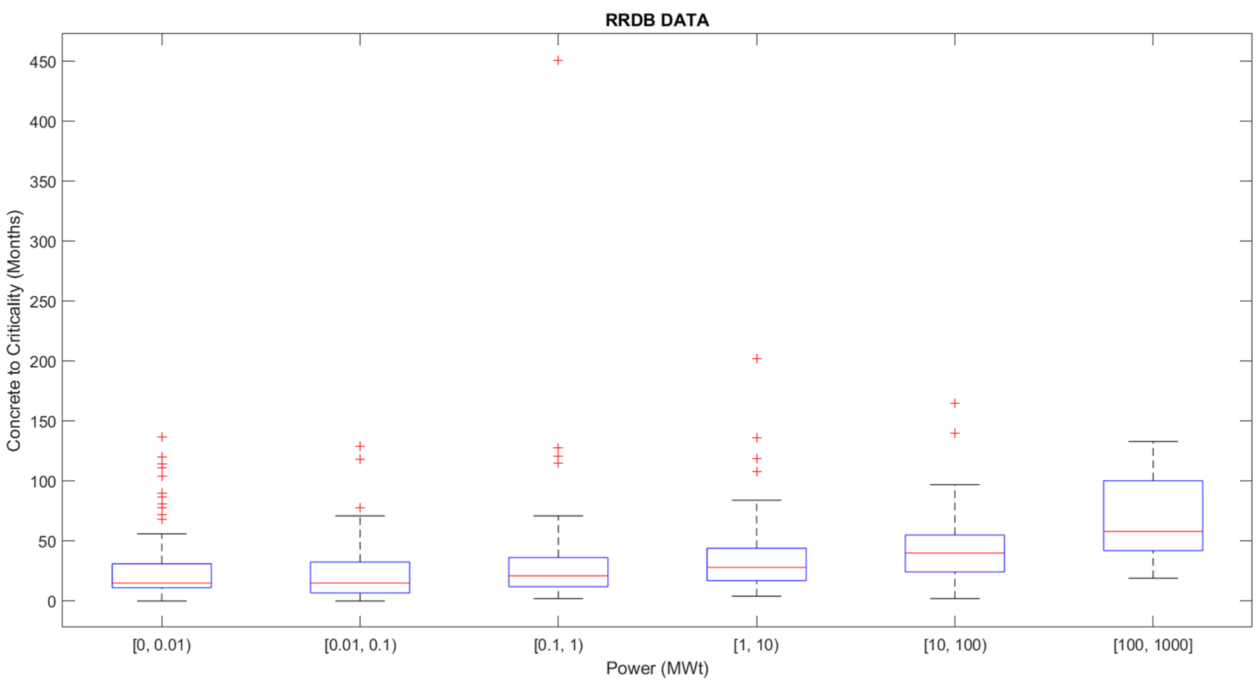

Figure 14. Box-and-whisker plot for research reactors, categorized by power output [2].

There are 99 research reactors with construction times and power outputs in the [1, 10) MWt range. Some highlights are the minimum construction time (4 months), the median construction time (28 months), and the mean construction time (34.8 months). Additionally, there are 87 research reactors with construction times and power outputs in the [10, 100) MWt range. Some highlights are the minimum construction time (2 months), the median construction time (40 months), and the mean construction time (44.3 months).

Lastly, there are 15 research reactors with construction times and power outputs in the [100, 1000] MWt range. Some highlights are the minimum construction time (19 months), the median construction time (58 months), and the mean construction time (66.2 months). A summary of the construction times associated with these reactors, categorized by power output, is shown in Table 6.

Table 6. Descriptive statistics for research reactors, categorized by power output [2]

Statistic	[1, 10) MWt	[10, 100) MWt	[100, 1000] MWt
Count	99	87	15
Mean	34.8 months	44.3 months	66.2 months
Median	28 months	40 months	58 months
Mode	17 months	12 months	107 months
Range	198 months	163 months	114 months
Minimum	4 months	2 months	19 months
Maximum	202 months	165 months	133 months
Q1	17 months	24 months	42 months
Q3	44 months	55 months	100 months
Upper adjacent	84 months	97 months	133 months
Lower adjacent	4 months	2 months	19 months
Outlier(s)	4 (108–202 months)	2 (140, 165 months)	none
Standard deviation	29.30	28.23	35.13
Kurtosis	11.549	3.930	-0.726
Skewness	2.8002	1.5139	0.6074

Comparing the descriptive statistics for the three categories shows a clear shift in the mean among the [1, 10), [10, 100), and [100, 1000] sets; as one would expect, construction time increases as the rated power increases, and the mean nearly doubles from the lowest to the highest categories. This shift is mirrored in the median time as well—more than doubling from the lowest to the highest categories. However, the highest category has the least skewness and the tightest range, indicating that the construction period for larger reactors tends to depend more greatly on the reactor itself, instead of the ancillary/auxiliary or associated research facilities.

3. POTENTIAL CONSTRUCTION SCHEDULES

3.1 CONSTRUCTION SEGMENTS

For advanced reactor construction, the primary segments are as follows:

- site selection
- site preparation for construction
- nuclear construction for reactor module
- reactor module factory fabrication
- on-site assembly and integration
- ancillary building construction
- startup testing

3.2 BASIS FOR ESTIMATES

For the US-based advanced reactor designs, exact construction methods and schedules have not yet been established. Therefore, estimates of the construction times were made based on the following factors:

- historical information from US-based large, light-water reactor deployment
- historical information from international advanced reactor deployment
- projected schedules from US-based advanced reactor vendors
- manufacturing analogs (US nuclear submarine manufacture, non-nuclear plant construction)

For this report, the best-case scenario was assumed—that is, the shortest estimated construction time for ARs. This provides a worst-case scenario for the available time for implementation of nuclear safeguards for a new advanced reactor design. This approach includes the following assumptions:

- reactor module is constructed at a factory facility in parallel to on-site construction
- just-in-time delivery of reactor module to construction site
- advanced reactor vendor deployment estimates are accurate
- no delays caused by licensing or export control
- safeguard implementation is not inherent to the design and will be performed by an external third party
- safeguards processes and equipment must be developed for advanced reactor types

3.3 EXCLUSIONS

Of the construction segments mentioned above, several were determined to be candidates for exclusion. The duration of site selection was excluded: this is outside the scope of construction activities for ARs and varies significantly, leading to unhelpful and unnecessary information.

Also excluded from the construction schedule estimates is the ancillary building construction segment. For advanced reactor designs, it is not yet known what ancillary buildings will be required, if any, and these will vary significantly from one design to the next. Any estimates in this area would not add value, so this information was excluded from the analysis.

3.4 SCHEDULE ESTIMATE

It is important to estimate the construction schedules for ARs to identify when and where there are opportunities to implement safeguards in the timeline. Specifically, the worst-case scenario for implementing safeguards will align with the lowest construction times. To this end, publicly available literature detailing the Westinghouse AP1000 PWR construction schedule was used to determine a low-end estimate of construction activities, as shown in the second column of Table 7 [1, 2, 3]. An anticipated construction schedule for the AP1000 was adapted from the IAEA [1], assuming a total construction duration of 36 months.

Table 7. Estimated construction schedules in months.

Activity	**AP 1000** [3, 4, 5]	Minimum AR estimate	Maximum AR estimate
Total pre-construction duration (order to first concrete pour)	***18.0***	***12.0***	***27.5***
Excavation	4.5	3.0	6.9
Total construction duration	***36.0*** (*a*)	***24.0*** (*c*) [2]	***55.0*** [2]
Nuclear island basemat	4.8	3.2	7.4
Internal concrete and steel modules	14.8	9.9	22.7
Set primary equipment	6.8	4.6	10.5
Turbine island basemat	10.6	7.1	16.2
Set turbine generator	4.8	3.2	(a)
Containment construction duration	***24.7*** (*b*)	***16.5*** (*d*)	***37.8***
First concrete to bottom head placement	4.9	3.2	7.4
Bottom head to lower ring installation	3.7	2.5	5.7
Lower ring to middle ring installation	11.0	7.3	16.8
Middle ring to upper ring installation	2.1	1.4	3.1
Upper ring to polar crane installation	1.6	1.1	2.4
Polar crane to top head placement	1.5	1.0	2.3

Note: all times are in months

The third and fourth columns in Table 7 detail minimum and maximum estimates of construction schedules for ARs, based on the Research Reactor Database's [2] first and third quartile of total construction durations for 10–100 MWt reactors: 24 and 55 months, respectively (see Table 6). The actual total construction durations [2], along with the proportions outlined in the second column in Table 7, were used to populate the third and fourth columns of Table 7. For instance, the minimum estimated duration of containment construction *(d)* (third column in Table 7) was calculated using Eq. 1.

$$d = b \cdot \frac{c}{a}, \tag{1}$$

where d is the minimum estimate of advanced reactor containment construction, b is the containment construction duration for the AP1000, c is the minimum estimate of AR total construction, and a is the total construction duration for the AP1000. Note that a, b, c, and d are measured in months and labeled in Table 7. The remaining entries in the third and fourth columns of Table 7 were determined using the procedure outlined in Eq. 1. The worst-case scenario for implementing safeguards is highlighted with a red outline in Table 7.

The worst-case scenario construction schedule for a generic AR may be established using the construction activities durations estimated in third column in Table 7 (outlined in red) and the construction schedule schematic shown in Figure 15.

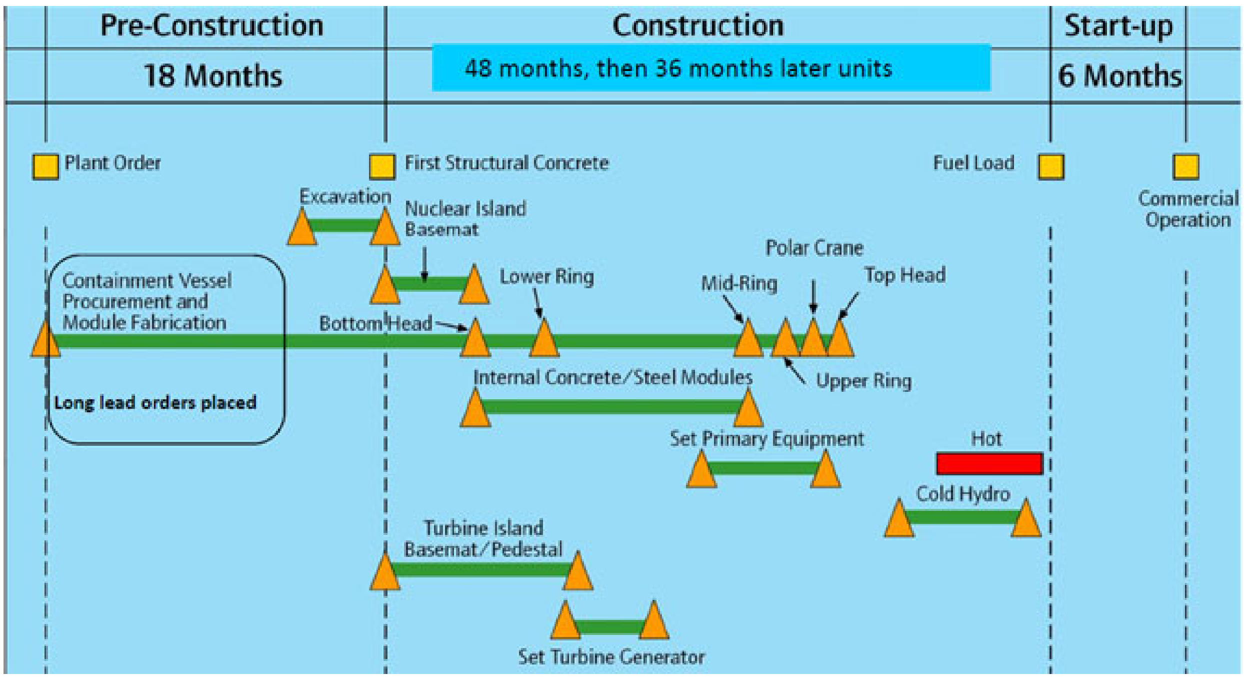

Figure 15. AP1000 construction schedule [3].

The worst-case scenario AR construction schedule is shown in the Gantt chart in Figure 16.

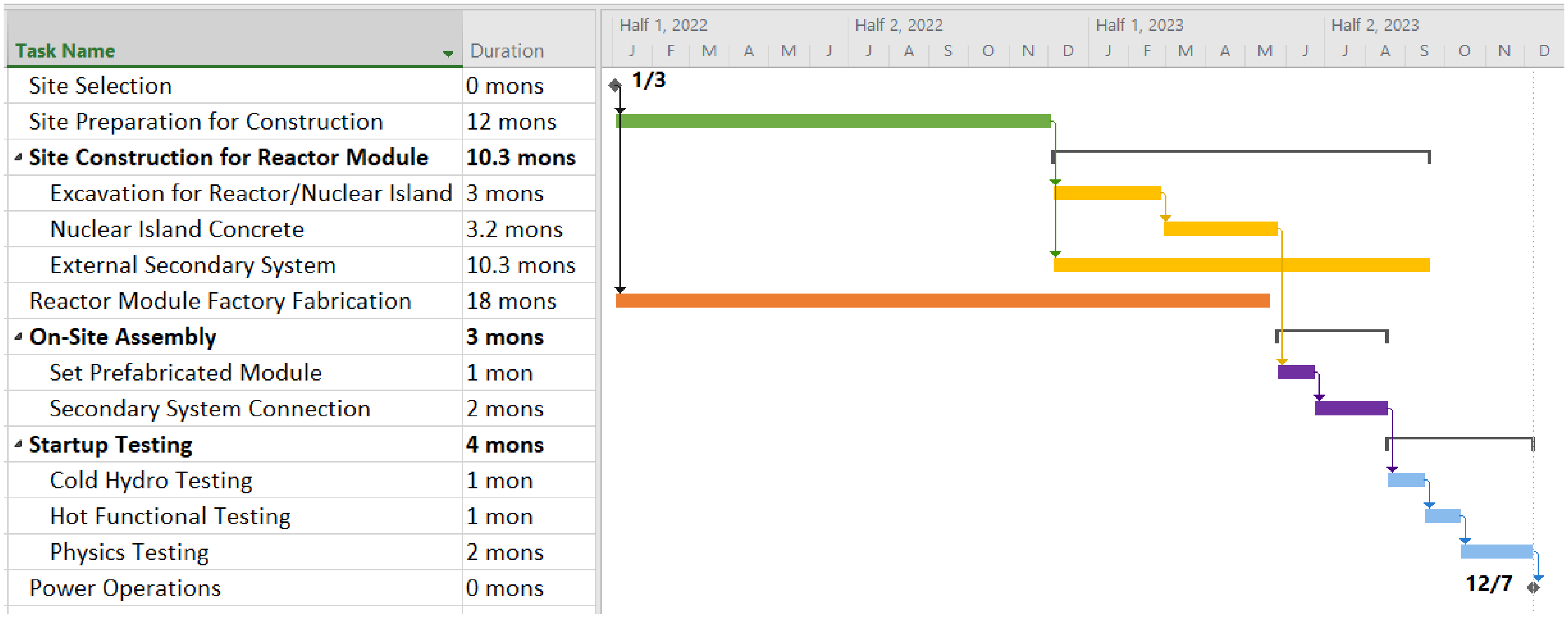

Figure 16. Best/worst case (shortest) construction schedule for a generic AR. Start date January 2022; all durations in months.

3.5 SCHEDULE RISK CHARACTERIZATION

This schedule has several inherent risks. Some of the items are forecast to be completed in parallel, for example, the nuclear island concrete and construction of external secondary side components, but these may be unable to be completed in parallel because of site layout, logistics, or lack of resources.

For some advanced reactor designs, there may not be any external secondary side construction. This could be combined with the reactor module, and it may reduce the on-site construction time significantly, providing less time for safeguards design and implementation.

Based on the historical analysis, construction and deployment times varied from those as-advertised by the vendor from two to four times the predicted completion times. This level of deviation makes useful predictions difficult to establish, which is why the as-estimated and as-built numbers for recent construction projects were used as a basis.

Additionally, as with any new reactor designs, licensing and regulatory activities are an integral part of the deployment of ARs. While these considerations were excluded from this paper, these activities remain closely tied to both construction and safeguards development. Associated regulatory approvals have the potential to impact key start-up and operational milestones if not proactively managed as part of an overall integrated schedule.

4. SUMMARY

Broad characterization of advanced reactor construction schedules is necessary to begin planning for safeguards implementation. Although an accurate and detailed schedule is not yet possible for the US-based advanced reactors, reasonable approximations can be made by drawing from the historical information of as-built US-based reactors and international analogs. Overall, the estimated fastest time from site selection to operation based on vendor and designer data supplied to the IAEA is just under two years; historical data based on research reactor construction suggests a reasonable expected construction period of approximately three years. Consideration for AR safeguard design and implementation with parallel timeframes can be expected and should be closely aligned with construction and licensing activities.

5. REFERENCES

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