RISK FRAMEWORK FOR NEXT GENERATION NUCLEAR POWER PLANT CONSTRUCTION

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ABSTRACT: This research documents the initial findings and recommendations for developing a risk management tool to assess and quantify the risks associated with the construction of the next generation of nuclear power plants. The proposed tool builds upon the Construction Industry Institute's International Project Risk Assessment (IPRA) Best Practice. This paper provides an overview of the investigation to assess the unique risk elements pertaining to nuclear power plant construction and documents the preliminary findings from historical project performance data to better understand the function and use of the IPRA's Relative Impact value.

Keywords: Construction Risk, Nuclear Power Plant Projects, International Project Risk Assessment (IPRA)

1. INTRODUCTION

Climate change concerns and global economic growth are driving resurgence in the construction of nuclear power plants. In general, new nuclear power plant construction continues to remain more expensive than coal, oil or natural gas [1]. However the emissions avoidance aspect of nuclear power makes it a promising source of carbon-free electricity. The Nuclear Energy Institute reports that as of May 2012, 66 new nuclear plants are under construction in 14 countries. The majority of plants under construction or in the planning stage are in the growing economies of Asia or Eastern Europe.

Risk and uncertainties abound in the planning and construction of nuclear energy power plants. New plant technologies, design and construction innovations, financing, and regulatory requirements are among the issues of concern [27]. The historical record of on-time and on-budget nuclear power plant construction is abysmal. In some cases, cost overruns were an order of magnitude in excess of the original budget. In the United States between 1966 and 1977, 75 reactors had cost overruns that averaged 207 percent, and more than 100 reactor orders were ultimately cancelled [25]. Recent low probability, high impact events have been catastrophic. The Fukushima accident brought forth concerns about site selection, safety, waste, and long term health effects [17]. Whereas operating nuclear plants are the lowest-cost producer of base load electricity, owners and contractors face enormous challenges to build the next generation of cost effective plants.

The motivation for this study was established by recognizing the demand and need to better identify and assess the risks associated with building the next generation of nuclear power plants from a comprehensive planning, design and construction perspective. Furthermore, given the complexity, costs, and duration of nuclear power plant design and construction, methods to identify and assess comprehensive project risks will promote a shared risk responsibility with accepted and proper allocations.

Risk assessment methodologies such as the Construction Industry Institute's (CII) International Project Risk Assessment (IPRA) tool have been developed and successfully used on a variety of heavy industry sector projects. The value of the IPRA has recognized construction with its recent elevation to Best Practice status however it lacks the specific focus to address the unique challenges of constructing the next generation nuclear power plant. The IPRA has proven to be a modifiable scheme having been customized for specific industry sectors including large-scale oil and gas. In fact, one of the recommendations identified by the original developers of the IPRA tool was that the Relative Impact value component of the IPRA gives general guidance on the rank order of risks, but because distinctive industry sectors bring unique challenges, risk assessment tools such as the IRPA should be enhanced to focus on a specific industry [30].

The following sections provide an overview of the initial research effort to assess the unique risk elements pertaining to nuclear power plant construction and the framework of historical project performance data to better understand the function of the IPRA's Relative Impact value.

Specific objectives of the study included:

- Investigate the adaptation of the existing IPRA risk assessment methodology for constructing the next generation of nuclear power plants
- Conduct a review and assessment of unique challenges and/or risk factors (elements) for constructing nuclear power plants
- If feasible, develop an enhanced version of the IPRA that addresses and encompasses the unique challenges of constructing nuclear power plant
- Develop a framework to collect and assess project-based performance data to qualify

and to better understand the function of the IPRA's Relative Impact value.

2. PURPOSE

The purpose of this research was to review and assess unique risk elements for constructing the next generation nuclear power plant projects, and to transform the IPRA risk tool to address the assessment needs for constructing nuclear power plants.

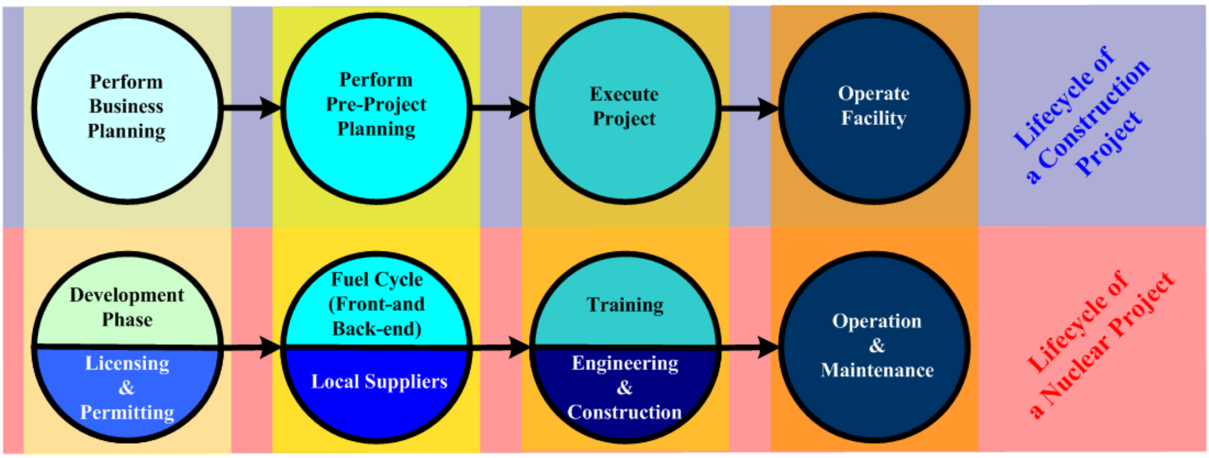
This research involved data acquisition, analysis, and an overview and initial assessment of how the IPRA could be modified to address the challenges of constructing the nuclear power plants. Furthermore, the research initiated the preliminary efforts to identify and collect project-based performance data to validate the selected risk elements and to better understand the function of the IRPA's Relative Impact value.

The remainder of this document begins with a brief introduction of the project lifecycle of a nuclear power plant, existing risk assessment for nuclear power plant projects, International Project Risk Assessment (IPRA) tool adopted for this study, the unique risk factors in constructing nuclear power plants, and the proposed modifications to the IRPA tool. The report concludes with the initial findings and recommendations for developing a comprehensive risk management tool to assess and quantify the risks associated with the construction of the next generation of nuclear power plants.

3. NUCLEAR POWER PLANT CONSTRUCTION

Nuclear power plant construction has a specific project lifecycle as shown in Figure 1. A prototypical construction project involves 4 steps: perform business planning, perform pre-project planning, execute project, and operate facility. Rather unique, the nuclear project development process is more complex and involves two types of life cycles that occur simultaneously. For example, because obtaining licensing and permitting can be tedious, extensive and heavily influenced by regulatory requirements, it must happen as a precursor or concurrently with the development phase in order to meet the proposed schedule. Similarly, safe operation and maintenance of the facility requires expert knowledge. Equipping and training the operations workforce requires much work including experienced instructors and adequate training centers much prior to actual operations. Thus, the training activities must take place concurrently with engineering and construction phase of the facility [28]. A host of issues including project complexity, long duration s, and concurrent activities make constructing a nuclear power plant more challenging than most other industry sectors.

Figure 1. Lifecycle comparison between a general project and a nuclear project



4. EXISTING RISK ASSESSMENT FOR NUCLEAR POWER PLANT PROJECTS

Procedures and processes exist to identify and assess nuclear power plant project risks, however few lifecycle viewpoints that focus on the construction aspects of such projects exist. The International Atomic Energy Agency (IAEA) developed the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) as a risk assessment tool to judge whether a constructed NPP is sustainable or not [4]. To determine risks, each NPP risk is selected or proposed by IAEA member states. Any organizations that are interested in construction and operation of NPP on a national, local, or international level can participate in this effort. Next, the shortlisted NPP risk elements are compared to a global standard. Lastly, discrete improvement factors can be added to improve the tool.

The U.S. Nuclear Regulatory Commission (NRC) also developed a Probabilistic Risk Assessment (PRA) tool [26]. The NRC PRA is used to estimate risk by determining likelihood and consequences in the design and operation of a NPP. Conducting a PRA analysis can assist in identifying design deficiencies and their relationship to the project. For example, an inadequate electrical system is considered an internal event, whereas natural disasters are considered an external event that could pose a threat or risk. The PRA process makes the connection between design, operations and the human and environmental impacts. For example, inadequate NPP design (level 1 PRA) can result in pollution, of the environment. As a result, the frequency (Level 2 PRA) of such contamination, and how this can impact humans (level 3 PRA) can be assessed. Current PRA assessments appear to give little or no consideration to the construction aspect of NPP projects.

5. THE INTERNATIONAL PROJECT RISK ASSESSMENT (IPRA) TOOL

The development of International Project Risk Assessment (IPRA) is rooted in CII's Project Definition Rating Index (PDRI). The PDRI tool offers a method to measure project scope definition for completeness. It provides the stakeholders a checklist for determining the definition of a project at the time of the analysis. In essence, the checklist is used to highlight areas where definitions are insufficient. The checklist includes elements of the project which the user can assign scores. Elements also contain various weights depending on how likely to introduce risk.

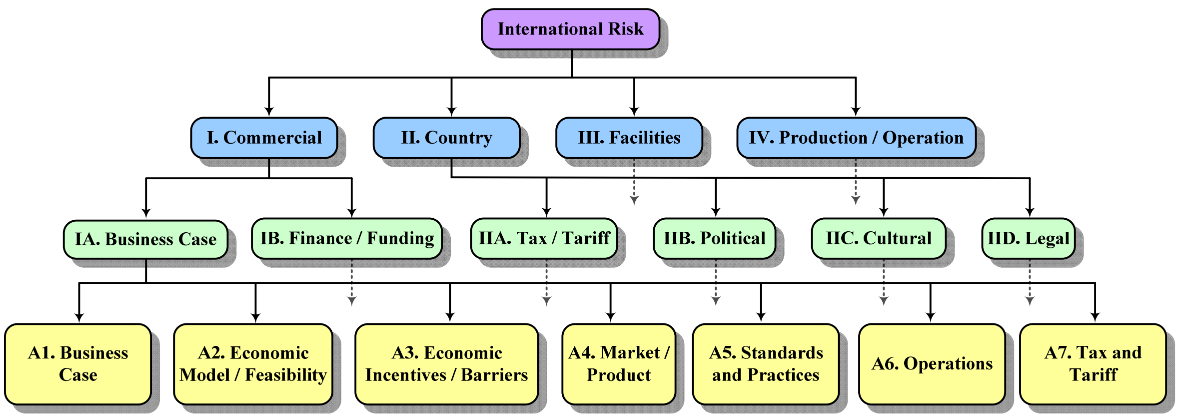
An advantage of the PDRI is that the construction manager is able to organize tailored strategies with respect to the unique risks of each project. For the owner, the PDRI provides well-prepared projects, aligns work groups, allow further assessment of practical risk, and optimizes project portfolio. For designers and contractors, the PDRI offers measured project scopes and establishes a bridgehead for vital communication among stakeholders and participants [7].

Based on the need for a process to enhance the assessment and management of international project risks, a structured risk identification and assessment process IPRA identifies and describes 82 issues that are the critical elements related to an international capital project and allows the project team to focus on risk factors of potential concern. The IPRA tool was validated on completed and ongoing projects representing 25 different countries and over $4.2 billion in total installed cost.

The methodology can be represented as a tree structure that consists of four levels. The first level encompasses all of the possible risk for the given international project. The international risk is initially broken down into 4 main sections which consists the second level. Each of these 4 main sections is further subcategorized into 14 categories which is the third level. The fourth level consists of detailed elements that are clear and easy for stakeholders to identify and score [29]. An element's risk involves two components: 1) the likelihood of occurrence, or in many cases, the likelihood that there will be a change to what is expected, and 2) the relative impact of that occurrence. The combination of the two factors using the IPRA Risk Matrix provides the coordinates to determine the Relative Importance of the risk.

The IPRA structure is shown in Figure 2.

Figure 2. Partial Structure of the IPRA [29]



6. UNIQUE RISK FACTORS FOR CONSTRUCTING NUCLEAR POWER PLANTS

The entire 82 IPRA risk elements were evaluated with regards to their applicability for nuclear power plant construction. From the onset, the research team hypothesized that there may be other significant risk factors unique to constructing nuclear power plants. Key sources of relevant publications and proceedings were reviewed which originated from International Atomic Energy Agency (IAEA), the Nuclear Regulatory Commission (NRC), the Organization for Economic Co-operation and Development (OECD) and the Center for International Governance Innovation (CIGI).

Based on a detailed literature review and analysis of historical performance of nuclear power plant construction, three key current IPRA elements were identified as significant risk issues during the development of such projects:

- ***Design changes (IPRA Section III., Element C1.)*** – Incomplete designs required re-engineering during the construction phase and other ripple effects. Since the design of NPP is complicated, a small change in design correlated with many other parts of the system leading to cost overruns and in severe cases lead to accidents**.**
- ***Financing (I. B1.)*** – Because private market's unwillingness to invest in nuclear power, the US nuclear industry relies on the government loan guarantee. Thus, the feasibility of the project depends on how much the congress appropriates for loan guarantees for nuclear power plant facilities. Even with innovative financing mechanism, the government is essential in supporting the generation of nuclear power plant construction by providing back-end guarantees because the risk is too high for private industry and utility providers.
- ***Economic Conditions (I. B2.)*** – External risk factors include economic conditions. The construction risk can increase when the demand for electrical power starts to decrease and the commodity costs increase which the owner has little or no control over.

The literature review also found four additional issues that have been historically problematic for the industry. Ranked in order giving consideration to possible impact significance and frequency of occurrence these consist of:

- ***Radioactive waste management (IPRA section V., Element A1. - NEW element)* –** The delay and failure of long-term disposal of spent nuclear fuel and waste has been a struggle for the nuclear energy industry. Without adequate space for waste repository, licensing new construction of nuclear power plants is also questionable.
- ***Lack of standardization (I. A5)* –** Insufficient rigor in radiation protection standard, reactor safety, plant siting, and environmental project were some of the safety and regulation concerns of critics. According to Atomic Industrial Forum (AIF), failure to meet baseline cost estimates was identified as failure of regulatory standardization policies and increased documentation to meet safety standards. Lack of standardization and increased documentation process lead to increase in material, equipment, labor and engineering effort and eventually cost overruns.
- ***Changing Regulation (II. D2.)*** – Because of the various approvals, legal processes, and political support that is required for nuclear power plant construction, risks associated with the investment, planning, design, and construction of such facilities is significantly impacted by the potential of changing regulations
- ***Recruitment (IV. A5)*** – Infrastructure challenge includes the lack of nuclear-sector construction experience and aging labor force. NPP constructions need to compete with other types of large investment projects such as oil and gas infrastructure exacerbating the need to find qualified workforce.

Table 1 provides a summary of the IPRA risks and their frequency from the data mining analysis. Elements are described with the corresponding IPRA Element number.. The literature used to conduct the analysis is above and beyond the list of references for this paper and includes over 25 technical and policy documents.

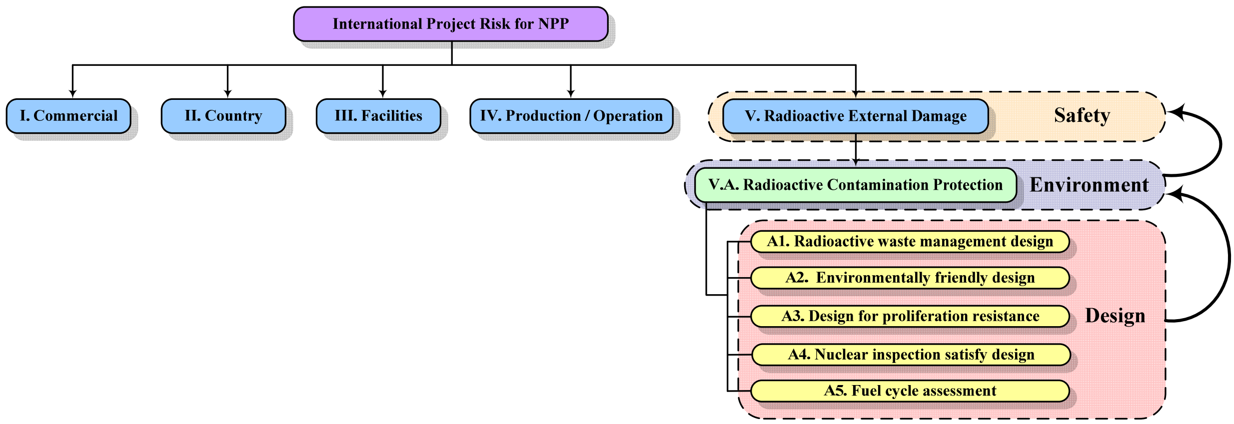
Table 1. IPRA Risks with Significant Frequency

IPRA Element	Element Description	Frequency
III. C1.	Design Change	17
I. B1.	Financing	12
I. B2.	Economic Conditions	9
V. A1.	Radioactive waste management	8
I. A5	Lack of Standardization	7
II. D2.	Changing Regulation	5
IV. A5.	Recruitment Conditions	3

7. THE ENHANCED RISK FRAMWORK FOR CONSTRUCTING NUCLEAR POWER PLANTS

A unique and new risk section was identified through this process. As the emphasis on environmental sustainability and biodiversity grew, both nuclear safety and disposal of radioactive waste were constantly debated. These concerns brought about issues related to the current status of the nuclear power plant design and operation including recommendation for future improvements. Thus, a fifth section was added to the existing IPRA tool to address damages that can be caused by radioactive waste. This section was further broken down into elements that ultimately affected the design and standardization of many construction techniques and components. Figure 3 shows the proposed enhanced risk assessment tool for the construction of next generation nuclear power plants.

Figure 3. The Proposed Risk Framework for Constructing Nuclear Power Plants



8. CONSISTENCY TEST

In order to verify that the issues identified are significant to constructing nuclear power plants, a preliminary list of project performance data was collected from historical data. (130 actual international NPP projects were observed.)

Project performance included cost and schedule information and identified or recorded causes for poor performance. Table 2 is an initial summary of previous work documenting 17 actual international project performances for nuclear power plant construction. New regulations, design problems, financing and accidents (concerns for safety) were consistently identified as major risks. Ongoing research by the authors continues to expand the assessment of previous projects. Furthermore, the authors are interested in exploring an enhancement of the IPRA's Relative Impact value using enhanced statistical methods using performance data from previous nuclear power plant projects. A comprehensive re-assessment of the research done to date is underway to expand the database of previously completed nuclear power plant projects. Whereas each of the projects are unique undertakings, the authors believe based on results to date, risks specific to the process of nuclear power plant construction can be categories into either existing IPRA elements or into the developed version including the new Section and Elements identified above.

An initial hypothesis in the development of the IPRA was that all risk elements are not equally important with respect to their likelihood of occurrence and relative impact on overall project success. For the IPRA, the best way to quickly develop reasonable and credible relative impact values for each element was to rely on the knowledge and experience from a broad range of construction industry experts. For future nuclear power plant projects, the desire is to develop depth and breadth regarding impact and occurrence after detailed historical project data is assessed and analyzed.

Table 2. Historical Project Performance Information

Project / Location	Cost Info	Financial Performance 1 to 5 scale[1]	Schedule Info	Cause	Reference
Metsamor, Armenia	Over Budget, Ongoing) ($4 billion → $ 5.2 ~ 7.2 billion)	2	Ongoing (2011 → 2017)	Lack of standardization	[10], [18]
Temelín, Czech Republic	Over Budget (35 billion CZK → 98.6 billion CZK)	1	Behind Schedule (1991 → 2000)	Recruitment Conditions	[3], [24]
Olkiluoto, Finland	Over Budget (€2.5 billion → € 5.8 billion)	2	Behind Schedule (2009 → 2015)	Radioactive Waste Management Lack of Standardization	[2], [20]
Flamanville, France	Over Budget (€3.3 billion → $8.5 billion)	2	Behind Schedule (2012 → 2016)	Design Change	[5], [13]
Superphénix, France	Over Budget (€9.1 billion → No info as a number)	-	Behind Schedule (1974 → 1981)	Economic Conditions	[22]
Kaiga, India	Over Budget ($141.75 million → $429.98 million)	1	Behind Schedule (1996 → 1999)	Financing	[23]
Monju, Japan	Over Budget (¥160-170 billion → ¥1.08 trillion)	1	Behind Schedule (1995 → 2010)	Incident	[8], [19]
Beloyarsk, Russia	Ongoing (No info as a number → $1.2 billion)	-	Ongoing (2012 ~ 2015)	Financing	[11]
Leibstadt, Switzerland	Over Budget (2 billion francs → 5billon francs)	2	Behind Schedule (No clear info as a number)	Changing Regulation	[9], [12], [15]

Project / Location	Cost Info	Financial Performance 1 to 5 scale[1]	Schedule Info	Cause	Reference
Gösgen, Switzerland	Over Budget (No info as a number)		Behind Schedule (February → November 1979)	Design Change	[14]
Longmen, Taiwan	Over Budget ($6.77 billion → $46.77 billion)	1	Behind Schedule (2009 → 2011)	Lack of Standardization	[16]
Hartlepool, UK	Over Budget (Increasing £25 million)	-	Behind Schedule (NPP is delayed in 1970)	Design Change	[21]
Sizewell A, UK	Over Budget (£56 million → £65 million)	2	Behind Schedule (No info as a number)	Design Change	[6]
Shoreham, USA	Over Budget ($ 350 million → $5.4 billion)	1	Behind Schedule (No info as a number)	Changing Regulation	[27]
West Valley, USA	Over Budget (Additional cost $2 billion)	2	Ongoing (From 1980)	Changing Regulation	[27]
Allied-General, USA	Over Budget (No info as a number)	-	Behind Schedule (No info as a number)	Financing	[27]
GE, USA	Over Budget (The final cost was $ 64 million)	-	Behind Schedule (No info as a number)	Financing	[27]

[1] *Scale of 1 to 5 with 1 being falling far short of expectations to 5 being far exceeding expectations.*

9. POSSIBLE RISK MITIGATION STRATEGIES

Possible risks can be mitigated by well-prepared strategies. Nuclear power plant projects require a set of clear standards for baseline cost estimation or legal standard to mitigate the risk factors. Given the work completed to date, the following initial guidance on mitigation related to nuclear power plant projects consists of the following strategies:

- ***Strategy 1. Baseline cost estimation standardization***

  The baseline cost estimations should be identified with regulatory standardization policies. This standardization will be the baseline for tracking project performance. Many trials and errors can be reduced by standardization. Comprehensive reviews of historical performance data can help standardize the baseline.

- ***Strategy 2. Local firms***

  Nuclear power plant construction firms should focus on hiring and utilizing local firms and laborers. Utilizing local firms within jurisdiction is an effective way to reduce the indirect costs.

- ***Strategy 3. Design standardization***

  Design should be standardized with respect to IAEA inspection standards, radioactive waste management system, and eco-friendly design. Given the complexity of the system design and many concurrent construction activities on site, streamlining and standardizing the design will reduce design errors and other negative ripple effects from design changes.

- ***Strategy 4. A high moral plane***

  Nuclear weapons can be made by uranium which will threaten countries surrounding jurisdiction. Annual nuclear inspection of IAEA should be allowed by the host country. To hinder contamination, nuclear waste should be disposed safely in an ethical way.

10. RECOMMENDATIONS

Nuclear power plants are promising and sustainable energy generators for the next generation. However, risk factors need to be clearly determined using a standardized risk assessment methodology. The IPRA is a sound and verified tool to assess international projects. The baseline IPRA was modified with unique and significant risk factors pertaining to construction of nuclear power plants. The most significant risk factors were related to lack of design standardization, safety, contamination, construction time reduction, budget saving, and radioactive waste disposal. This was initially obtained from the literature survey and confirmed through an initial assessment of historical project performance.

One of the major concerns was that uranium for heavy water type nuclear power can be converted into nuclear weapons. To address the environmental, safety and design concerns a few mitigations strategies were proposed in this study. There should be more standardization for design strategies and budgeting purposes. Local firms and workforce should be utilized to reduce cost overruns. Countries should manage the use and disposal of nuclear waste transparently with respect to national standards. Also, periodic nuclear inspection of jurisdictions should be accompanied by IAEA staff. To avoid contamination, environmental sensitive designs are required for the safety of those in and around such facilities.

This study reports on the preliminary findings for developing an enhanced risk framework for constructing nuclear power plants. For advanced level verification the proposed elements, further work is underway to document previous project performance and assess those with additional quantification methods and compare these with the original Relative Impact values developed for the IPRA. Further steps in creating a nuclear power plant-pecific risk assessment methodology include verification by experts and validation of project performance data over the life cycle of such projects.

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