

Site Substitution Analysis of Small Nuclear Reactor Construction in Thermal Power Plant Site

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Abstract

With the development of Chinese economy and society and the acceleration of the urbanization process, the demand of centralized heating is increasing day by day. On the other hand the traditional coal-fired heating method is not only inefficient, but also exacerbates the environmental pollution. Therefore, this paper explores the feasibility of using existing thermal power plant sites to build small nuclear reactors. This paper first summarizes the basic principles of the site selection of small nuclear reactors, Subsequently, the basic factors that should be considered in the site selection process are elaborated. Based on the substitution analysis of the plant site, taking the Xiayuan power Plant as a research object, its geographical location, population distribution, nuclear emergency feasibility were comprehensively evaluated. The study shows that it has certain technical feasibility to build a small nuclear reactor at the site of the existing thermal power plant.

Keywords: Component, Small Nuclear Reactor, Clean Heating, Plant Location

1. Introduction

With the development of Chinese economy and society and the acceleration of the urbanization process, the demand for residential heating is increasing. On the one hand, the heating area is increasing year by year, and many areas in northern China are facing the problem of heat source shortage; on the other hand, Chinese central heating mainly relies on cogeneration and coal-fired boiler, the fuel is still mainly coal, the emission of coal pollutants is one of the main reasons of winter haze in northern China. Therefore, a clean, efficient, and economical heat source that meets the needs of large-scale central heating is urgently needed.

Low-temperature nuclear heating technology has been used abroad since the 1950s. In 1989, Tsinghua University built Chinese first special low-temperature shell nuclear heating reactor in Changping, Beijing. In 2017, the China Institute of Atomic Energy conducted a demonstration and experiment on pool reactor heating in Fangshan, Beijing. In the same year, the National Development and Reform Commission, together with

the Ministry of Environmental Protection and other ten ministries and commissions, issued the Plan for Clean Winter Heating in Northern China (2017-2021), which clearly proposed to strengthen clean heating technology innovation, explore nuclear heating, and safely develop low-temperature swimming pool heap heating demonstration. At the beginning of 2018, the National Energy Administration held a symposium on winter nuclear energy heating in northern China, requiring the research and development and demonstration application of small reactor nuclear energy heating technology, and to do a good job in public communication [1]. At present, China National Nuclear Corporation has carried out the preliminary work of low-temperature nuclear heating projects in Xabu, Liaoning province, China General Nuclear Power Corporation in Xingtai, Hebei province and State Power Investment Group in Baishan, Jilin Province.

At present, Chinese energy structure is still dominated by coal and oil, and the air pollution is more serious. In recent years, the country has actively taken measures to reduce emissions, and

many small and medium-sized thermal power plants are facing closure and decommissioning. Using the site layout, power grid access and partial infrastructure of existing thermal power plants, the difficulty and cost of construction and transformation can be reduced compared with new nuclear power plants. For some thermal power stations with old facilities and high maintenance cost, combined with the technical achievements and practical experience of modular small reactors, transforming transformation into a new safety intelligent modular small reactors nuclear power plants, will be a new idea to improve economic benefits [2]. Accelerating the construction of small modular reactors (SMRs) to replace traditional energy sources is imperative for addressing issues related to energy structure and the associated environmental concerns. This article first outlines the fundamental principles and factors for selecting sites for SMRs, then it provides a detailed and systematic analysis of how geographical location, natural environment, population distribution, and meteorological conditions influence site selection. Additionally, it assesses the feasibility of repurposing retired thermal power plants to reduce the investment required for constructing SMRs. The paper offers a comprehensive evaluation of the factors involved in nuclear site selection, providing theoretical support for the siting of small modular reactors.

2. Basic Factors and Work Outline for Site Selection

2.1. Basic Principles

The basic principles for the siting of small modular reactors (SMRs) primarily refer to the Chinese national standard NB/T 20293-2014, "Basic procedures for site selection of nuclear power plants." These principles can be summarized as follows, ensuring that the selected site meets the requirements for nuclear safety, environmental protection, and socio-economic development: To follow the national nuclear safety regulations and meet the requirements of the current national design regulations, standards and norms; Domestic mature small heating nuclear reactor technology route (such as ACP100+) is selected to determine the natural and technical conditions of its site selection.

Give full consideration to the characteristics of the pile site and the external natural events or human events that may occur in the area, and select the site suitable for reconstruction and construction to meet the requirements of the general layout [3]. According to the Code for Design of General Plane and Transportation of Nuclear Power Plant, and cooperate with the general site planning of the decommissioned power plant, to meet the requirements of physical security, fire protection, emergency, construction bulky transportation and flood control [4]. The design of the plant and supporting facilities shall meet the requirements of safety, reliability and economy.

2.2. Basic Factors in the Selection of Nuclear Power Plant Sites

Safety and reliability factors: mainly external events affecting the nuclear power plant safety that may occur in the plant area, including external natural events such as earthquake, geology, hydrology, meteorology and external man-made events such as explosion and aircraft crash [5].

Environmental compatibility factors: including site environmental characteristics of population distribution, land and water utilization, and nature reserves, which may affect the diffusion route of released radioactive materials to human body and the environment, as well as site characteristics related to the feasibility of implementing emergency plan and individual and group risk assessment [6].

Technical feasibility factors: including technical measures related to site safety protection and ring compatibility, as well as the technical feasibility of site use conditions, power grid access conditions, drainage and drainage conditions, transportation and other related factors; Economic rationality factors: including the investment cost of major technical measures related to safety and reliability, environmental compatibility and technical feasibility, as well as the site factors related to the economic benefits and input cost of nuclear power plant construction.

2.3. Outline of Site Selection for Small Nuclear Reactors

2.3.1 Geographic Location Analysis

The modular small reactor uses an integrated reactor technology and a completely passive safety system. It can realize the minimum area of emergency planning area, planning restricted area and non-residential area. The modular small reactor construction project uses the existing site of the old power plant for renovation and construction, and the non-residential boundary of the modular small reactor construction project can usually be consistent with the boundary range of the thermal power plant, which also meets the standard requirements of the Safety Evaluation Principles for Small pressurized water Reactor Nuclear Power Plant (Trial). The distance between the boundary of the planned restricted zone and the reactor is generally not less than 1km. In addition, also need to consider the specific environmental characteristics around the reactor (such as terrain, administrative boundaries, population distribution, traffic and communications, etc.) social and economic conditions and public psychological factors, probability risk assessment (PSA) report work, evaluation of the accident, must be confirmed by the local peoples government at the provincial level, to eventually delimit the residential and the actual boundary of the restricted area.

2.3.2 Analysis of the Surrounding Situation of the Site

Nuclear power plants should avoid environmentally sensitive areas such as scenic spots, nature reserves and drinking water source protection areas. The environmental impact of the project on the scenic tourism areas and nature reserves shall be evaluated, and the construction permission of relevant departments shall be obtained. The living facilities around the factory site are perfect to meet the living facilities for the construction of the nuclear power plant. The transportation around the site should be very convenient to facilitate the construction of nuclear power plant and the transportation of fuel and waste. Have the transportation conditions for nuclear power plant construction.

Should complete the site environment and its external man-made events investigation and statistical project report, the site

near the amphibious ecological environment investigation and analysis and evaluation report, to evaluate the surrounding natural ecological situation, to evaluate the project construction impact on the environment, evaluate the project construction of the scenic tourist area and nature reserve, and obtain the relevant department construction permit.

2.3.3 Regional Population Analysis.

According to the relevant guidelines for site selection of nuclear power plant and the requirements of environmental impact statement, the population and age composition of all communities or administrative villages and natural villages within 5km of the site shall be investigated, the population composition in recent years of all communities or administrative villages, towns or streets within 5-15 km, and the population distribution within 15-50 km. According to the population density method recommended by the National Nuclear Safety Guidelines for Population Distribution (HAD101 / 03), the type of project site is judged [7]. On this basis, based on the expected population growth rate of a certain area, the population growth model is used to predict the population distribution within the evaluation range in the first year of operation and every 10 years later.

2.3.4 Feasibility Analysis of Nuclear Emergency Response.

If a nuclear power plant is established at the site of the decommissioned power plant, the operating unit and the local government shall supplement the relevant contents of nuclear and radiation emergency response, so that they can have the functions of nuclear accident emergency radiation monitoring, data processing and analysis, accident consequence evaluation and decision support, and meet the requirements of current regulations and emergency plans. The emergency system of the plant shall establish a contact mechanism with the local government departments to ensure the smooth flow and linkage of the emergency system, and the emergency facilities can be put into operation in time in case of accidents.

2.3.5 Hazard Source Analysis

According to the Nuclear Safety Guidelines "External Human Events in the Selection of Nuclear Power Plant Site" (HAD101 / 04), ammunition, oil, inflammable, explosive and corrosive items, toxic chemical warehouse and weapon testing site within 5km radius of the site should be investigated. The impact of fixed hazard sources is to calculate the safety distance of potential explosives around the site according to HAD101 / 04 External Man-made Events of Nuclear Power Plant Site Selection. The calculation formula is as follows as [8,9].

$$R=KW^{1/3} \quad (1)$$

In formula:

R is shock wave fortification safe distance, m;

Mass or equivalent of TNT of W explosion source, kg;

K is fortification safety factor (value 18), m /kg.

2.3.6 Analysis of Background Radiation Status

The radiation environmental quality monitoring data of each region in the 2022 National Radiation Environment Quality Report published by the Radiation Environment Monitoring Technology Center of the Ministry of Ecology and Environment can be used to explain the current situation of the radiation environment quality at the site where the project is located. The environmental monitoring of ionizing radiation cited in this project mainly includes environmental γ radiation level monitoring such as continuous automatic monitoring of environmental γ radiation dose rate and cumulative monitoring, as well as the monitoring of radionuclide activity concentration in environmental samples such as air, water, soil and biology.

Monitoring of ionizing radiation includes field monitoring and sample collection and laboratory analysis. On-site monitoring is continuous automatic monitoring of radiation environment automatic monitoring station (referred to as "automatic station", the same below). The automatic station data is transmitted to the provincial and national data centers through the communication network, monitors the change of environmental γ radiation level through the data management system combined with the meteorological data, and alarms to the abnormal data. The content of artificial radionuclides is a key indicator to evaluate the impact of radioactive substances on the environment and public health in normal operation or emergency situations. In order to identify the trace amount of artificial radionuclides existing in the environment, the radiation environmental monitoring, in addition to the automatic monitoring of the automatic station, must also collect various environmental samples for laboratory analysis.

2.3.7 Meteorological Analysis

In order to estimate the extent to which the radioactive materials released by nuclear power plants diffuse to the residential areas and evaluate the radiation impact on people, atmospheric data must be fully mastered. In the site survey stage, the conventional meteorological data and turbulence data of the nearby meteorological station are required; in the site evaluation stage, the plant meteorological station should be established to conduct field meteorological observation for diffusion calculation and statistical analysis, and use these data to find the probability distribution of the concentration of radioactive substances released by the nuclear power plant, and then accurately evaluate the suitability of nuclear power plant construction from this data [10].

2.3.8 Hydrological Analysis

According to the Flood Control Standard (GB50201-2014), the final design base flood level of the nuclear power plant shall not be lower than the highest hydrological record or historical flood level. For the nuclear industry and factories, workshops and specialized facilities related to nuclear safety, the flood control standard higher than once in 1000 should be adopted, and the once in a thousand years should be checked to further determine the base flood.

2.3.9 Geology, Earthquake and Civil Engineering

To collect the existing geological, seismic and geophysical data,

supplemented by the necessary site survey work, to make a preliminary evaluation of the geological and seismic conditions of the candidate sites. Make the geological and seismic characteristics and the stability of the site of the site, such as the seismic structure and active fault; the potential geological disasters caused by the earthquake; make the preliminary determination of the seismic intensity of China (1990); make the preliminary estimation of the high value of the seismic parameter SL-2 of the site; and provide the preliminary engineering geological data required for comparison, comprehensive analysis and evaluation of the candidate site.

2.3.10 The Overall Factory Site Plan

Make the preliminary site master planning and possible construction scale according to the site conditions of the site, the existing equipment and the engineering composition of the nuclear power plant.

2.3.11 Plant Site Safety Evaluation

According to the safety regulations of nuclear power plant

site selection and the requirements of relevant guidelines, a preliminary safety evaluation is made for each candidate site, and its acceptability is judged.

3. Site Selection Analysis of Decommissioning Power Plants Overview of Thermal Power Plant

The project is located in Xiayuan Power Plant in Xiayuan District, Zhangjiakou City, Hebei Province, which is industrial land. The geographical coordinates of Xiahuayuan District are east longitude 115°16 and north latitude 40°29, covering an area of 303.997 square kilometers. The surrounding area is adjacent to Huailai County, Xuanhua District, Zhuolu County and Pangjiapu Town, and about 162 kilometers away from Beijing. The power plant is surrounded by Beijing, Baotou railway, Minsheng Road, Yanghe River and Daijiaying River. Plplan to transform decommissioned thermal power plants into small nuclear power plants. The power plant covers a total area of about 290 mu, including the decommissioned old plant and 210MW units in service. The project defines the boundaries of non-residential areas as illustrated in Figure 1.



Figure 1: The project assumes the boundary range of non-residential areas

3.1. Site Substitution Analysis

Based on the aforementioned principles, the subsequent plant suitability analysis is summarized in Table 1:

Location elements	Analytical conclusions and suggestions
Geographic location and population distribution	<p>geographic position</p> <p>The project uses the existing site of Xihuayuan Power Plant for renovation and construction, and the land area is about 27.20hm². The non-residential boundary of the project can be consistent with the boundary range of Xihuayuan Thermal power plant, and also meets the standard requirements of the Safety Evaluation Principles for Small pressurized Water Reactor Nuclear Power Plant (Trial).</p> <p>The distance between the boundary of the planned restricted area and the reactor shall generally not be less than 1km, and most of the streets around the site of the project are located within this range.</p> <p>Follow-up work also need to consider the specific environmental characteristics around the reactor (such as terrain, administrative boundaries, population distribution, traffic and communications, etc.), social and economic conditions and public psychological factors, probability risk assessment (PSA) report work, evaluation of radioactive consequences caused by accident, must be confirmed by the local peoples government at the provincial level, to eventually delimit the residential area and planning restricted area actual boundary [11].</p>

	The situation around the site	<p>Xihuayuan District of Zhangjiakou city is located in the warm and semi-arid area of Sangyang Basin. It is a continental monsoon climate, with four distinct seasons and complex stratigraphic structure, mostly mountains and hills. The factory site is surrounded by provincial wetland parks and town streets. The surrounding natural environment meets the natural conditions of nuclear power plant construction.</p> <p>The living facilities around the plant site are perfect to meet the living facilities for the construction of the nuclear power plant.</p> <p>The transportation around the site is very convenient for the construction of nuclear power plant, fuel and waste transportation. Having the transportation conditions for nuclear power plant construction.</p> <p>Follow-up should be completed around the site environment and its external human event investigation and statistical project report, near the site of amphibious ecological environment investigation and analysis and evaluation report, to evaluate the surrounding natural ecological situation, to evaluate the impact of the environment, evaluate the project construction of the environmental impact of scenic tourist area and nature reserve, and obtain the relevant department construction permit.</p>
Industry, transportation, and military installations	population distribution	<p>99.7% of the site within 50km belongs to Zhangjiakou City, Hebei Province. Although the site of the Project is close to the urban built-up area, the population density is low within 40km; the relatively densely populated towns and villages within 15km are not located under the main wind direction of the site.</p> <p>Preliminary judgment, population distribution is not the construction constraints of the project.</p>
	Nuclear emergency feasibility	<p>Xihuayuan Thermal power branch has emergency facilities to meet the needs of non-discharge emergency response. If a nuclear power plant is established at the site, the operating unit and the local government shall supplement the relevant contents of nuclear and radiation emergency response in accordance with the above principles, so that they can have the functions of nuclear accident emergency radiation monitoring, data processing and analysis, accident consequence evaluation and decision support, and meet the requirements of current regulations and emergency plan. The emergency system of the plant shall establish a contact mechanism with the local government departments to ensure the smooth and linkage of the emergency system, and the emergency facilities can be put into operation in case of accidents.</p>
	Fixed hazard sources	<p>The current fixed hazard sources near the factory site include dangerous goods storage facilities (gas stations) and pipelines transporting oil, gas or other dangerous substances (civil natural gas pipelines).</p> <p>Two of the gas stations had a potential risk of explosion, which affected the site selection.</p>
	Mobile hazard source	<p>Mobile hazard sources near the site include the potential sources of explosion on transport lines (railway and highway) and the probability of aircraft crash.</p> <p>Assuming that when the potential explosion source of the Beijing-Bao railway explodes, it will have a great impact on the safety of the project, it is suggested that special attention should be paid to evaluating whether the Beijing-Bao railway is transported before determining the site selection.</p> <p>In addition, the impact of flying objects (including airport routes and military facilities) and toxic chemicals should be further analyzed after the data is complete.</p>
	crime of sabotaging weaponry military installations or military telecommunication	<p>In the future, the distance between the project site and military facilities and the information related to weapons and equipment, such as the distance between military airfields and live-bombing exercise areas, should be collected. Further evaluate its impact on the plant site.</p>
	Current status of the environmental radiation level	<p>The radiation environment quality in the area where the project site is located is generally good.</p>
meteorological phenomena	<p>The location of the project is a temperate continental monsoon climate, no tornado or typhoon invasion, except for thunderstorm, other disaster climate is rare. The atmospheric stability in the area where the factory site is located is mainly found in class D.</p> <p>Based on the available data, there is no meteorological data indicating that the Lower huayuan site is not suitable as a nuclear power site.</p> <p>It is suggested to obtain the meteorological observation data and turbulence data of nearby meteorological stations, as well as establish the site meteorological station and obtain the meteorological observation data for at least one consecutive year, and then accurately evaluate the suitability of nuclear power plant construction with this data.</p>	
hydrology	<p>The Yanghe reservoir is built 22 kilometers upstream of the Yanghe reservoir and was built in 1973. It is suggested that further special demonstration on the safety of the reservoir structure should be carried out to determine whether the downstream is at risk of flood impact after dam break.</p> <p>The site lacks the data of the highest historical flood level and the data of flood level in 1000 years; Check the Preliminary Design Report of the flood control dam or level elevation, and the qualified unit shall be entrusted to conduct flood control demonstration.</p> <p>Yanghe River is a seasonal water shortage basin, and the flow rate, water level and flow rate change greatly during the year. For example, the Yanghe River as a warm water area has a great impact on water quality and quantity and the ecological environment of Yanghe River. It is not recommended to use Yanghe River as the final heat trap of nuclear power plants.</p>	

Geology, earthquake, and civil engineering	The geological structure of the proposed site is complex, and there are active faults from the late Pleistocene to the Holocene in the near area. The seismic intensity is high, the bedrock roof is large, and the construction cost is high.
	It is suggested to further investigate whether there are active faults and rock mass that potentially affect the safety of the nuclear power plant and can be used as the foundation bearing layer of the plant and conduct seismic safety evaluation, so as to further determine whether they are suitable for construction.
Safety analysis and radiation environmental impact assessment	Compared with the emission of radioactive gaseous outflow in Changjiang Small reactor, combined with the meteorological conditions of the site of the project, it is preliminarily predicted that under the operation condition of the project, the maximum annual effective dose is below the 0.06 mSv / a of the project, and the radiation effect of gaseous outflow radiation is acceptable. According to the results of Chang Jiang small heap location hypothesis accident analysis, using conservative meteorological assumptions and guidelines recommended conservative algorithm, calculate the public individual of the project, during the accident by the maximum effective dose of 9.24 mSv, meet the small pressurized water reactor nuclear power plant safety review principle (trial) in the dose requirements. Therefore, from the perspective of accident analysis, the project site is appropriate[12].
Storage and transportation of new fuel, spent fuel and radioactive solid waste	The existing roads near the plant site meet the relevant requirements for the transportation of spent fuel and radioactive solid waste.

Table 1: Outside1Comprehensive evaluation table of site selection elements

Based on the data provided by the power plant and the research results of the design institute, and referring to the laws, regulations and technical specifications related to the site selection of nuclear power plant construction, the site is preliminarily identified as having the technical feasibility of the construction and operation of ACP100 + modular small reactor and the corresponding site characteristics. However, at present for the site selection elements assessment still shortcomings, even some key data is missing, so need to further collect and investigate the site related topography, population distribution, land use situation and resource information, and should be issued by the corresponding qualifications of institutions on regional meteorological and site meteorological observation, water hydrology analysis of the report. After completing a series of work such as site leveling planning, seismic safety evaluation, topographic survey, geotechnical engineering survey, hydrogeological survey, geological disaster risk assessment and environmental impact assessment, it is necessary to evaluate the safety reliability and environmental compatibility of the site further in combination with the relevant policy requirements of the local government. Finally, on the basis of ensuring scientific, systematic and comprehensive, the conclusion is drawn about whether the existing thermal power plant site is suitable for the construction of heating nuclear reactor [13].

4. Conclusion

This paper draws upon a comprehensive study of the traditional nuclear power plant selection process and relevant laws and regulations to identify key elements for the site selection and implementation framework of modular small nuclear reactors (SMRs), while also analyzing various alternative cases in the construction of SMR projects. In light of the identified shortcomings in the current specific specifications for SMRs, it remains essential to adhere to the standard requirements established for traditional nuclear power plants during the actual site selection process. Looking ahead, it is imperative to leverage the expertise

of industry professionals and scholars to advance the construction and development of SMR demonstration projects in inland areas, thus fostering the expansion of nuclear power applications beyond coastal regions.

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