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Water Resources Assessment and Management for Nuclear Power Plants in China

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Abstract

To deal with global warming and energy shortage, nuclear power plants are constructed or planning to be constructed in China presently. The operation of a nuclear power plant consumes a great amount of water and discharges a lot of radioactive wastewater into nearby marine or freshwater environment. Therefore, water resources assessment and management are crucial to this kind of plants considering their significance to not only marine and freshwater environment protection but also sustainable development of nuclear power industry. This article proposed the contents, procedures and methods of water resources assessment and management for nuclear power plants based on the overview of development process of nuclear power plants in China. Furthermore, the tendency of water resources assessment and management for nuclear power plants in China was also presented. Water resources assessment for a nuclear power plant in China should analyze local water resources, the rationality of water-draw and utilization of a plant, water sources, the impact of water-draw and wastewater discharge as well as water resources safety mainly. The key processes of it may include data collection, compiling a work outline, analyzing local water resources as well as water-draw and wastewater discharge of a plant, and completing and approving the report. The suggested methods of it are referring legal documents, site investigate, model simulation, expert consultation and public participation. Finally, suggestions, including carrying out comparison as well as selection of several optional sites, improving impact assessment of radioactive wastewater discharge and enhancing public participation, are also proposed.

Keywords: nuclear power plants, water resources assessment, water resources management

Introduction

To meet the demands of energy supply and greenhouse gas emission mitigation, China has implemented policies of adjusting energy structure (Chen et al., 2009) and exploiting new energy (Wang, 2009). Among the new energies, nuclear energy is considered as the most effective and sustained one to deal with energy problems in China (Sovacool, 2008; Jasmina et al., 2012). Therefore, China issued *Medium and Long-term Development Plan of Nuclear Power (2005 to 2020)* in 2007 to promote nuclear power industry (Zhou, 2010). Even after Fukushima Dai-ichi nuclear power plant accident, China also issued *The 12th Five-Year Plan and 2020 Vision of Nuclear Safety and Radioactive Pollution Prevention and Control* (National Nuclear Safety

Administration of Ministry of Environmental Protection of the PRC, NDRC, Ministry of Finance of the PRC, National Energy Administration of the PRC, the Commission of Science, Technology and Industry for National Defense of the PRC, 2012) in October, 2012 and made a decision of resuming the construction of nuclear power plants (China's State Council, 2012). The operation of a nuclear power plant consumes a great amount of water and discharges a lot of radioactive wastewater into nearby marine or freshwater environment. Therefore, water resources assessment (WRA) and management of the plants are critical to not only water resources conservation but also sustainable development of nuclear power industry.

However, the assessment and management system haven't been completely established in China, especially for inland nuclear power plants which are still in the planning phase. The objectives of this research are to propose the contents, procedures and methods of WRA and management for nuclear power plants and present some suggestions on improving it in the future. Considering that inland nuclear power plants have more serious effects on water resources (Butkauskas et al., 2012), this article focuses on water resources assessment and management for inland plants.

Theory System of Water Resources Assessment for Nuclear Power Plants in China

Different from other countries with inland nuclear power plants, China has dense population and most people take surface water as drinking water source (Liu et al., 2013). In addition, China has prominent contradiction between water supply and demand (Shen, 2010) as well as limited water environmental carrying capacity (Qu and Fan, 2010). So WRA for nuclear power plants in inland China should particularly concern the three aspects (Ding et al., 2013). Firstly, operation of an inland nuclear power plant consumes a great amount of fresh water (Genk and Mohamed, 2008), which further intensifies competition for limited water. Secondly, a nuclear power plant discharge cooling water and radioactive wastewater, which has a great influence on local water quality (Abbaspour et al., 2012). Thirdly, under accidental conditions, a tremendous amount of middle or high-level radioactive wastewater may directly discharge into natural water bodies and cause a series of water environmental disasters (IAEA, 2011). The theory system of WRA for nuclear power plants in China which includes the contents, procedures and methods is proposed as followings.

Contents of Water Resources Assessment for Nuclear Power Plants in China

According to *Guidelines of Water Resources Assessment for Construction Projects (Trial) (SL/Z322-2005)* (Ministry of Water Resources of the PRC, 2005) and the characteristics of nuclear power plants in inland China, WRA for the plants should mainly include the following contents (Table 1): analysis of the current condition and development of water resources in the site area, rationality analysis of water-draw and utilization, water sources assessment, impact analysis of water-draw and wastewater discharge, and water resources safety evaluation for accident conditions and emergency measures. As far as the part of rationality analysis of water-draw and utilization is concerned, the suggested values of major water use indicators are as shown in table 2.

Table 1. WRA for nuclear power plants in inland China.

No.	Item	Content
A	analysis of the current condition and development of water resources in the site area	a) for analysis scope: water resources quantity and its time-space distribution characteristics; the quality of water resources; nature, society and economy conditions; water resources supply and demand; the situation and potential of water resources development;
		b) for site area: utilization level of water resources; major problems of water resources development and utilization.
B	rationality analysis of water-draw and utilization	a) rationality of water-draw: relationship between the project and regional industrial structure, state industrial policy, regional water resources condition, as well as allocation schemes of water resources; impacts of water-draw on regional water resources allocation, other water users, and even regional water utilization structure;
		b) rationality of water utilization: water use and consumption; the generation and treatment of polluted water and wastewater; water balance and the values of water use indicators; pollution reduce measures; adverse impact of water utilization;
		c) the potential of water-saving: the rationality and advancement of water use and water-saving; water use level; water-saving potential; appropriate water-saving measures; reasonable amounts of water-draw and water utilization.
C	water sources assessment	a) available water quantity in water-draw region and watershed;
		b) water quality of water-draw area;
		c) the rationality of inlet setting;
		d) the reliability and feasibility of water-draw.
D	impact analysis of water-draw and wastewater discharge	a) the impact of water-draw;
		b) the impact of wastewater discharge;
		c) the rationality and feasibility of outlet setting and reasonable wastewater discharge schemes;
		d) water conservation measures;
		e) mitigation schemes for adverse impacts.
E	water resources safety evaluation for accident conditions and emergency measures	a) the probability of different grades of nuclear accidents;
		b) radioactive wastewater discharge schemes under accident conditions;
		c) the impact of radioactive wastewater discharge on water resources security;
		d) emergency measures and the applicability and feasibility.

Table 2. Major water use indicators of WRA for nuclear power plants in inland China.

No.	Indicator	Implication
1	cycling rate of indirect cooling water	percentage of cycling and reuse indirect cooling water in the total indirect cooling water
2	reuse rate of steam condensate	percentage of reuse steam condensate in boiler steam output
3	reuse rate of water resources	percentage of reuse water in the total water use
4	water-draw amount per 10^4 kWh	water-draw amount for generating electricity of 10^4 kilowatt hours
5	water-draw and consumption amounts per million kilowatts capacity	water-draw amount of per million kilowatts capacity, water consumption amount of per million kilowatts capacity
6	growth rate of water utilization	the ratio of the increment of annual water use and water use amount of the previous year
7	compliance rate of wastewater discharge	percentage of compliance amount of wastewater discharge in the total amount of wastewater discharge

Procedures of Water Resources Assessment for Nuclear Power Plants in China

The procedures of WRA for a nuclear power plant in inland China is put forward and includes: (a) site survey, site investigate and data collection; b) the assessment agency compiling the work outline of WRA; c) the related watershed authority approving the outline and provide necessary suggestions; d) the assessment agency modifying the work outline and making a work plan; e) analyzing the current condition and development of water resources in the site area, evaluating the rationality of water-draw and utilization based on the schemes proposed by the construction unit, and assessing the reliability and feasibility of water sources (i.e. surface water); f) impact analysis of water-draw and wastewater discharge; g) completing the first draft of WRA report, consulting experts and presenting the modified one to the watershed authority; h) the watershed authority approving the modified report preliminarily, providing comments and submitting it to Ministry of Water Resources of the PRC (MWR); i) MWR carrying out technological review and administrative approval; j) accomplishing final WRA report (if the application is approved) or applying for re-approval or modifying inappropriate water-related designs (if the application is rejected). Figure 1 shows the proposed procedures of WRA for nuclear power plants in inland China. Figure 2 shows that of impact analysis of water-draw and wastewater discharge.

Methods of Water Resources Assessment for Nuclear Power Plants in China

A) Referring legal documents

WRA for nuclear power plants in inland China is a legal process to guarantee the security of inland water resources. So it should follow relevant laws, regulations, specifications, standards, nuclear power industry plans and water resources development plans. The documents includes *Water Law of the PRC* (Order [2002] No.74) (National People's Congress, 2002), *Management Approaches of Water Resources Assessment of Construction Projects* (Order [2002] No.15) (MWR, 2002a), *Claim on Enhancing Water Resources Assessment Work of Constructing Projects* (MWR, 2002b), *Water Resources Assessment of Construction Projects* and *Guidelines of Water Resources Assessment for Construction Projects (Trial) (SL/Z322-2005)* (MWR, 2005), *Integrated Wastewater Discharge Standard (GB 8978-1996)* (Ministry of Environmental Protection of the PRC, former General Administration of Quality Supervision, Inspection, and Quarantine of the PRC, 1996), *Environmental Quality Standard for Surface Water* (GB 3838-2002) (Ministry of Environmental Protection of the PRC, General Administration of Quality Supervision, Inspection, and Quarantine of the PRC, 2002), *The 12th Five-Year Plan and 2020 Vision of Nuclear Safety and Radioactive Pollution Prevention and Control*, etc.

B) Site investigate and survey

Sites investigate and survey is helpful for assessors to understand nature, society, economy characteristics of site area, especially the conditions of water resources development and utilization. It also helps them to identify potential risks and find water-related problems. Assessors may focus on issues related to water consumption and wastewater discharge, such as inlet setting, wastewater treatment facilities, outlet setting, water resources statuses of water-draw and receiving water bodies, and public's perception and attitudes. In particular, records, photographs, videos about site investigate and survey should be preserved.

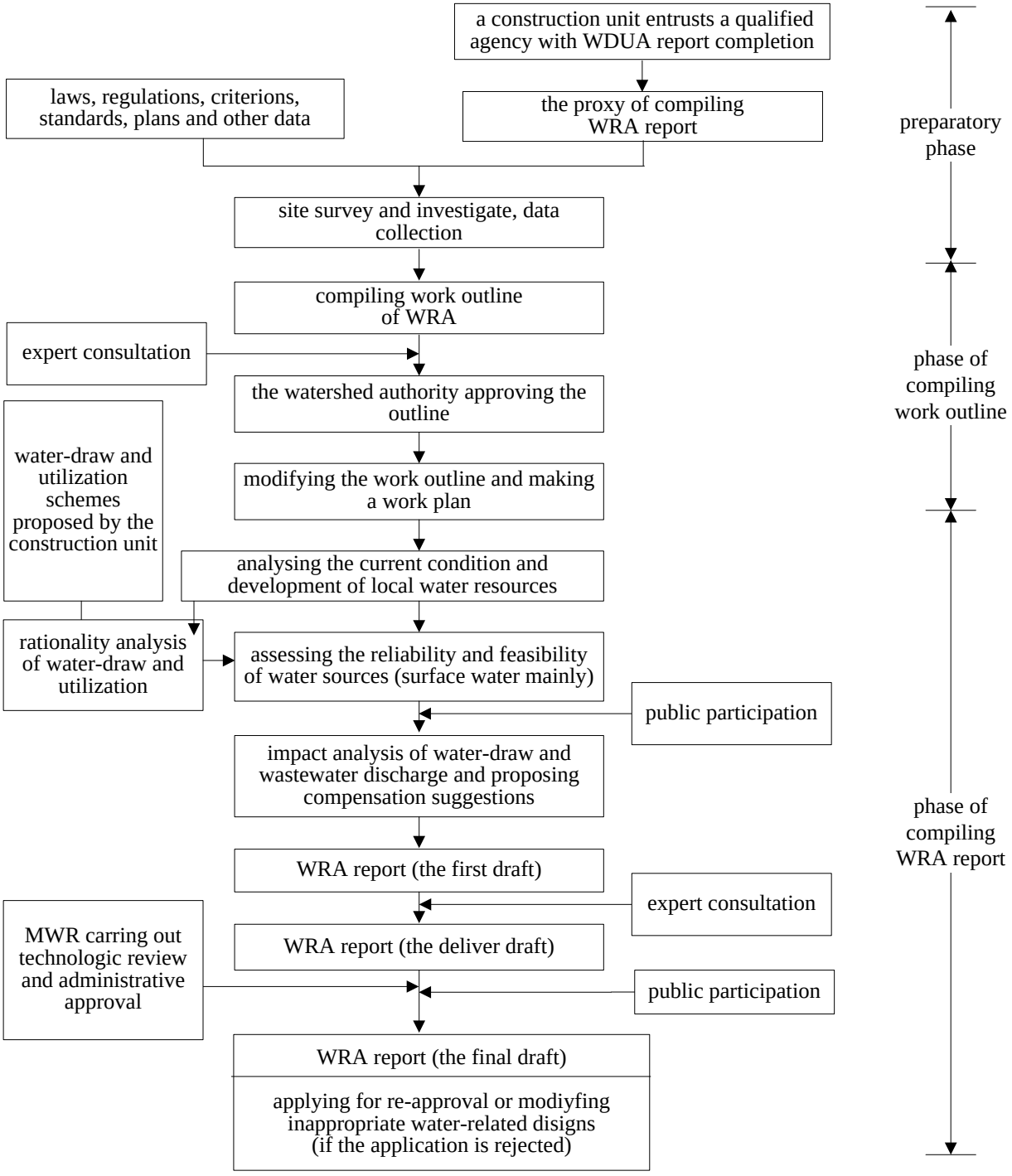

Figure 1. Procedures of WRA for nuclear power plants in inland China.

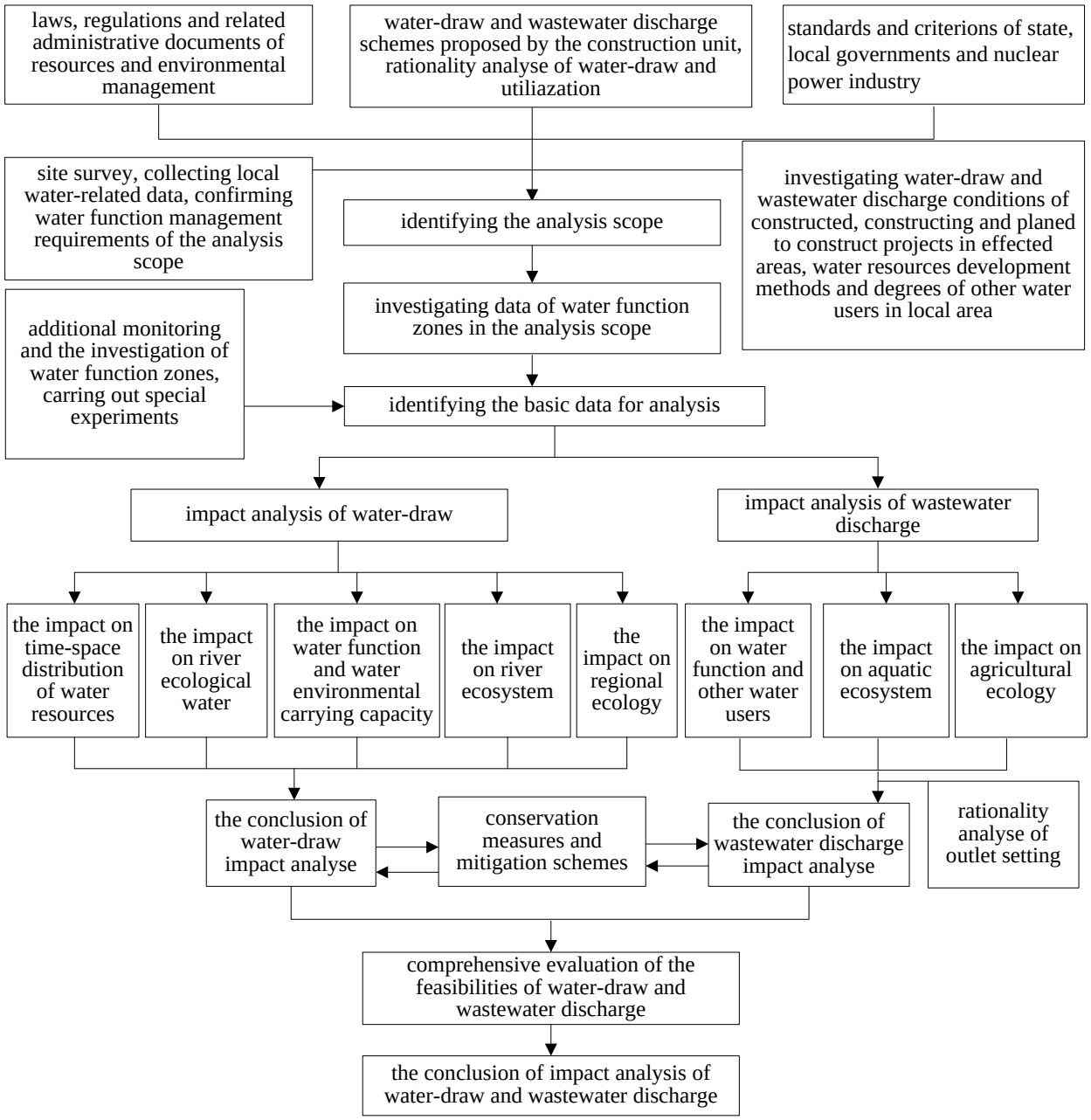

Figure 2. Process of impact analysis of water-draw and wastewater discharge.

C) Model simulation

An inland nuclear power plant is a new thing in China, and the adopted technology advanced passive 1000 (AP1000) pressurized-water reactor technology is also an innovative one without any practical experience. So data referring or field monitoring of similar plants is infeasible, and model simulation becomes an important method to carry out WRA. The impact of water-draw and wastewater discharge under normal conditions, the impact of wastewater discharge under accident conditions, and the effects of emergency measures could be assessed by hydrodynamic models (Tsumune et al., 2012), water quality models (Huang et al., 2010) and watershed

management ones (Laguionie et al., 2012). The common models include realizable k - ε turbulence model, Joseph model, instantaneous point source model, etc. The usable softwares are FLUENT, MIKE, SMS and so on.

D) Expert consultation and public participation

Expert consultation is important for that of nuclear power plants in inland China considering that it is unprecedented, with high technical requirements, and gets great attention. It helps assessors to make a more effective work outline, carry out more reasonable evaluation, and propose more feasible suggestions. The forms of it are report review, discussion, holding colloquia, etc.

In China, surface water is the most important drinking water source and the contradiction between water demand and supply is prominent, which are different from other countries with inland nuclear power plants. Public pay high attention to nuclear power plants in inland China. One reason is that water-draw and utilization of the plants would greatly affect other water users of local watersheds. Another reason is discharge of wastewater (particularly that under accidental conditions) may seriously contaminate drinking water sources. Thus, public participation is legal and significant for WRA due to its high public's sensitivity. Posting notices, releasing information on internet, door-to-door interviewing, holding hearings and model simulation (Visschers and Siegrist, 2013) are methods and the accepted opinions or reasons for rejecting should be recorded in WRA reports.

Prospect of Water Resources Assessment for Nuclear Power Plants in China

Comparison and Selection of Several Optional Sites

Nowadays, WRA for a nuclear power plant in inland China is carried out for a confirmed site. It is difficult for assessors to deny a site for huge investment and manpower in previous years, even though it is not suitable considering current situation of water resources. Water resources management departments can merely provide some suggestions and comments on the premise that the site location is final. But in future, WRA should be involved in planning and siting stages of the plants. The assessment could concern several optional sites. Assessors could compare and select a site (or sites) considering more water-related qualifications, such as the distance between plants and local water bodies, the minimum runoff (including annual and instantaneous ones) of water-draw water bodies, the space between outlets and drinking water sources and so on. By this way, conditions related to water resources can be considered further in preliminary stages.

Impact Assessment of Radioactive Wastewater Discharge on Water Resources

Under normal working conditions, low-level radioactive wastewater is discharged. Impact assessment of it on water resources involves transport and decay processes of radioactive substances in receiving water bodies, cumulative effects of radioactive substances on aquatic organisms and so on. Such issues are complicated and interdisciplinary (e.g., hydrology, radiology, and biology), which might be studied by the support of MWR and related watershed authorities. In addition, under accident conditions, medium or high-level radioactive wastewater may be discharged into receiving water bodies. The scope, duration and degree of the effect

should be assessed quantificationally. So appropriate models, monitoring methods and even simulation softwares are expected to be proposed in the near future.

Public Participation

For nuclear power plants in inland China, most of receiving water bodies have drinking water sources downstream. The discharge of radioactive wastewater which has various adverse impacts on water quality and aquatic ecosystem may probably arouse great public concerns. Public participation is an effective way to resolve possible water disputes, improve the effectiveness of WRA decision-making, and reflect the democracy of WRA. The degree of public participation should be enhanced during the entire process of WRA. In the future, the impacts of water-draw, water use and wastewater discharge on local water resources should be released by various channels in time. Public prediction model might be used to reflect the sensitivity of public concerns, and forms and approaches of it for WRA will be also specified and unified.

Conclusions

Nuclear power is important to deal with climate change and energy shortage. In the near future, nuclear power plants will be operated in inland China, which poses great challenges to China's water resources management. Water resources assessment is a critical way to evaluate the rationalities of water-draw, water utilization as well as wastewater discharge of the plants. The contents of water resources assessment for a nuclear power plant in inland China mainly are suggested to include analysis of the current condition and development of water resources in the site area, rationality analysis of water-draw and utilization, water sources assessment, impact analysis of water-draw and wastewater discharge as well as water resources safety evaluation for accident conditions and emergency measures. The key processes of water resources assessment proposed are site survey and data collection, compiling a work outline and making a work plan, analyzing the current condition and development of local water resources, rationality analysis of water-draw and utilization, assessing the reliability and feasibility of water sources, impact analysis of water-draw and wastewater discharge, completing the first draft of the report and modifying it, Ministry of Water Resources of the PRC carrying out technological review and administrative approval, accomplishing final report or applying for re-approval or modifying inappropriate water-related designs. Methods of water resources assessment for nuclear power plants in inland China may contain referring legal documents, site investigate and survey, model simulation, expert consultation and public participation. In the future, water resources assessment for nuclear power plants in inland China should be improved in the aspects of comparison and selection of several optional sites, impact assessment of radioactive wastewater discharge on water resources, public participation and so on. It is expected that the assessment will be more effective and become a powerful management tool to support sustainable utilization of water resources and security development of nuclear power industry in China.

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