China's Response to Nuclear Safety Pre- and Post-Fukushima: An Interdisciplinary Analysis

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Abstract

The Fukushima Daiichi nuclear disaster has rekindled the world's attention to nuclear safety following the devastating nuclear accidents that occurred in the Three Mile Island and Chernobyl. As China continues to expand in nuclear power development, how it views and responds to nuclear safety carries significant implications on its nuclear safety and security in the future. This paper examines the Chinese authorities' response to nuclear safety pre- and post-Fukushima, based on (1) a longitudinal big-data discourse analysis of the Chinese newspaper articles published during the period 2008-2017, and (2) an in-depth comprehensive review of nuclear safety performance and safety governance based on credential and publicly available documents and websites, both locally and internationally. Our assessment reveals that (i) China's concerns over nuclear safety and accident surged immediately following the Fukushima crisis. Increasing attention towards nuclear emergency response has been observed since 2014, (ii) China has displayed strengths in reactor design and safety operation, and (iii) its safety governance has been constrained by institutional fragmentation, inadequate transparency, inadequate safety professionals, lack of a strong safety culture, amid its ongoing plans to increase nuclear capacity three-fold by 2050. To improve nuclear safety, China may further strengthen its safety standards, safety management and monitoring, improve institutional arrangements, increase the ratio of safety professionals, intensify its safety culture and transparency, develop process-based safety regulations, and champion international collaboration to keep itself abreast of the latest international best practices.

Highlights

- China's concerns over nuclear safety have surged following Fukushima
- China displays strengths in reactor technology design and safety operation
- China needs to improve in safety management, institutional integration, safety culture, transparency, regulatory design and international collaboration.

Keywords: nuclear safety, discourse analysis, comprehensive assessment, pre-Fukushima, post-Fukushima, China

Word count: 1,0161 words

List of abbreviations: BDE, Beyond the Design basis Events; CAEA, China Atomic Energy Agency; CNEA, China Nuclear Energy Association; EPR, European Pressurized Reactor; CDF, Frequency of Core Damage; IAEA, International Atomic Energy Agency; INES, International Nuclear and Radiological Event Scale; IRRS, Integrated Regulatory Review Service; LRF, Frequency of Large Release; MEP, Ministry of Environmental Protection; NDRC, National Development and Reform Commission; NEA, National Energy Administration; NEC, National Energy Commission; NNSA, National Nuclear Safety Administration; NPP, Nuclear Power Plant; OSART, Operational Safety Review Team; RINPO, Research Institute for Nuclear Power Operations; Term Frequency–Inverse Document Frequency, TFIDF; TMI, Three Mile Island; USNRC, US Nuclear Regulatory Commission; WANO, World Association of Nuclear Operators; WNA, World Nuclear Association

1. Introduction

Japan's Fukushima disaster reawakened the world's concerns for nuclear energy safety. The meltdown of three reactor cores at Fukushima Daiichi following the Tōhoku earthquake and tsunami was rated by the International Atomic Energy Agency (IAEA) as a Level 7 incident, the highest level on the International Nuclear and Radiological Event Scale (INES) [1]. In the wake of this, anti-nuclear sentiments surged markedly in many countries [2-4], and the safety of nuclear power plants (NPPs) all over the world was called into question [5]. Such sentiments contradicted the continual dependence of the countries on nuclear energy as a clean, reliable and affordable source of electricity [6]. Some governments opted to shut down their nuclear reactors or shelve plans for new plants [7], while others, such as Germany, plan to close all of its NPPs by 2022; Some countries, such as the UK recommitted to building new reactors to replace old ones. Whilst the expansion of nuclear energy projects was expected to be slow in many developed countries [8], developing countries, such as China and Russia, continued to rely on nuclear power for energy security and low-carbon objectives. A radical shift in nuclear power policy in these countries seems unlikely [9, 10].

There are reasons why nuclear safety in China deserves careful attention. China has one of the most ambitious nuclear power development [11, 12] (Figure 1). In 2013, nuclear power is made up of 2% of China's total electricity generation. By 2017, it was increased to 4% [13] and was projected to increase to 15% by 2050 [14]. In 2018, China had 45 commercial NPPs in operation, 15 under construction, and many more under development [13] (see Figure 2 for the geographical distribution of NPPs in China and Table A2 for more details). Given the long lifespan of the commercial NPPs in China, the old NPPs will pose a real burden for decommissioning in the coming decades. By 2050, around 10 GW reactors will have been decommissioned in China based on the time that they started operation and their design life [15]. This massive and rapid development of commercial NPPs in China has put enormous pressure on nuclear safety. Given that China has been rapidly expanding its nuclear capacity, and incorporating new nuclear design models from France, Canada etc., the following concerns arise. Firstly, has China kept abreast of the progress in nuclear safety and safety culture, given the rise in nuclear capacity, challenges of nuclear design, construction, operation and maintenance, and plans for decommissioning?

Secondly, will China's current institutional arrangement that oversees nuclear safety regulations, guidelines, and procedures provide an effective safety mechanism for such a mega project and sufficient safeguards against catastrophic nuclear accidents? Thirdly, are China's NPP meeting the IAEA safety standards?

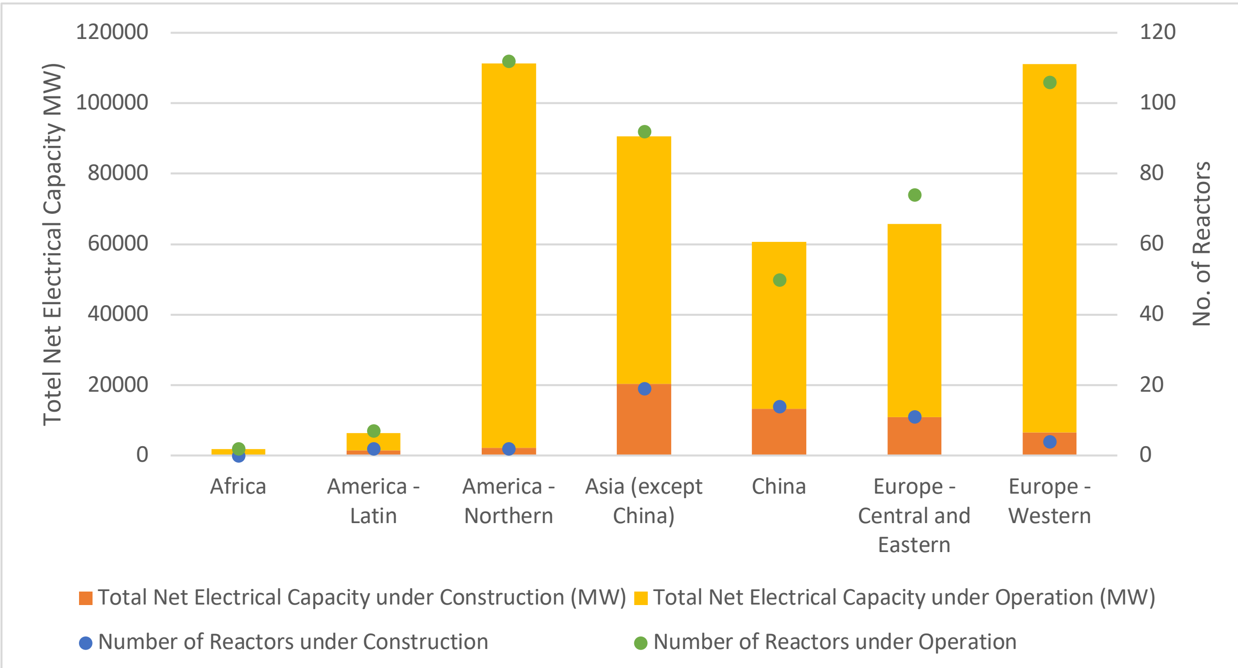

Figure 1. Number of nuclear reactors in operation and under construction by country. Source: [11, 12]

Figure 2. Nuclear power stations in China (2018). Source: [13]

With a population of 1.3 billion, how China perceives and responds to nuclear safety concerns will carry significant implications on its own safety and security. This paper explores three key questions. Firstly, what is the Chinese authorities' perspective of nuclear safety following the Fukushima crisis? Secondly, what are China's documented responses to nuclear safety? Thirdly, are the responses genuine or rhetoric?

Our analysis is structured as follows: First, a longitudinal big-data discourse analysis is conducted to identify the views expressed over nuclear safety through a large quantity of newspaper articles [16, 17]. Discourse analysis serves as an effective means to decipher the Chinese authorities' concerns over nuclear safety issues in situations when directly obtaining views on nuclear safety via direct personal interviews is not achievable. Second, safety performance and policy analyses are conducted to assess the nuclear safety performance and the governance of NPPs in China. Last, we evaluate whether China's current response to nuclear safety is genuine or rhetoric, with suggestions on ways to improve nuclear safety in China.

2. Methodology

2.1 Method 1: Statistical Discourse Analysis

To gauge China's concern for nuclear safety, it is possible to conduct a qualitative discourse analysis based on the newspapers that are representative of the government's views. However, this task has become increasingly challenging as researchers are required to handle large quantity of textual information. In contrast, statistical discourse analysis offers a "systematic, objective, quantitative analysis of message characteristics" [18], and has become a useful tool to complement qualitative analysis in many domains including policy and media studies [19, 20].

Newspaper texts were used in this study for several reasons. Firstly, official documents are not always publicly accessible and tend to be prescriptive. Secondly, official documents generally take longer to draft and publish and may not be able to capture the dynamic socio-political changes timely. Newspaper reports permit continuous tracking of evolving events (e.g. the Fukushima disaster) on a daily basis. Lastly, media texts in China are usually indicative of up-to-date policy foci and direction [21]. In China, state-run newspapers represent key channels through which state views related to policy issues are expressed and shared with the public [22, 23]. The primary English-language newspaper in China, *China Daily*, is state-run and facilitates the dissemination of official information, including policy implementation. More than 80% of the newspaper coverage represents the views of the Chinese administration [24]. Systematic tracking of news reports over time can minimize potential bias from individual documents or interviewees. Though such materials may not capture the full views of the administration, the change in views reported in the news media can serve as a proxy reflecting its changing concerns over nuclear safety before and after the Fukushima disaster.

Three English state-run newspapers were selected for this research. Despite a difference in readership between these three publications and their Chinese counterparts, the English newspapers shared similar functions insofar as they represent the views of the Chinese administration. Another reason for using English newspapers is that computational mining tools can produce better and more reliable results when working on English texts as opposed to Chinese texts. The news articles selected were those published in the *China Daily*, *Shanghai Daily* and

Shenzhen Daily newspapers, during the period of 11 March 2008 to 10 March 2017. *China Daily* was the first state-run national English newspaper in China, which is considered the English language equivalent of the *People's Daily*. It is the most authoritative official newspaper and serves as a key mouthpiece of the Chinese Communist Party [25]. *Shanghai Daily* and *Shenzhen Daily* provide comprehensive news coverage at the regional level in China [26]. Most of the opinions covered by these three state-run English newspapers were quoted from official sources [24]. Articles were retrieved from the *Wisenews* news archive portal (URL: http://www.wisers.com/corpsite/global/en/home/index.html). We first selected newspaper articles that contain the word "nuclear" in their headlines. We then further refined our search and selected articles that contain (*"nuclear power" OR "nuclear energy") AND "China"*. Articles were verified manually to confirm their relevance. A total of 234 articles were collected, covering a nine-year period. We defined the period starting before 11 March 2011 as the pre-Fukushima period, and the period on or after 11 March 2011 as the post-Fukushima period. To compare the changes in attention over nuclear safety, the corpus was equally divided into three sub-corpora, namely (i) pre-Fukushima sub-corpus (2008-2011), (ii) post-Fukushima sub-corpus (2011-2014), and (iii) post-Fukushima sub-corpus (2014-2017). The details of the selected articles can be found in Table 1.

Table 1. Period covered and size

Sub-corpus	**Period**	**No. of Files**	**No. of Words**
Pre-Fukushima	Year 1 (Mar 11, 2008-Mar 10, 2009)	19	28,459
	Year 2 (Mar 11, 2009-Mar 10, 2010)	24	
	Year 3 (Mar 11, 2010-Mar 10, 2011)	16	
Post-Fukushima (1)	Year 4 (Mar 11, 2011-Mar 10, 2012)	37	41,882
	Year 5 (Mar 11, 2012-Mar 10, 2013)	28	
	Year 6 (Mar 11, 2013-Mar 10, 2014)	15	
Post-Fukushima (2)	Year 7 (Mar 11, 2014-Mar 10, 2015)	29	44,803
	Year 8 (Mar 11, 2015-Mar 10, 2016)	29	
	Year 9 (Mar 11, 2016-Mar 10, 2017)	37	
Total	Year 1-Year 9 (Mar 11, 2008-Mar 10, 2017)	234	115,144

The text mining software package T-Lab Version 7.3 (URL: http://www.tlab.it) was used to perform quantitative statistical analysis (see [27] regarding the use of T-Lab for data mining). The advantage of using T-Lab for text analysis is that the quantitative analysis is not simply based on word counts. Though three newspapers may report the same event, for example, a speech made by a politician, the importance of such event would not necessarily be three times more important than another speech reported only once in one newspaper. T-Lab detects the keywords of relatively high information load and statistical significance based on the distribution across news articles. For example, term frequency–inverse document frequency (TFIDF) is a well-attested information retrieval measure that discounts high frequency words that have less information value [28].

A. High Frequency Word List: The most frequently occurring words were extracted from each sub-corpus for preliminary comparison. They can indicate the major issues discussed in the sub-corpora.

B. Specificity Analysis: This method was previously used to compare the semantic variations across various sub-parts of a corpus by examining lexical units [29, 30]. It identifies lexical units that typically belong to a certain sub-corpus according to the chi-squared test applied to all the intersections of the contingency table constructed by the lexical units and their corresponding sub-corpus. It highlights the different distributions of lexical items in the three sub-corpora and shows how the discourse foci change across the sub-corpora.

C. Thematic Analysis: This method was previously used in a wide range of studies across different disciplines [19, 31-33] to automatically uncover the major themes (topics) of a text corpus. The analysis has been applied in this study to identify the potentially prominent themes (topics) and the relevant lexical items that fall under those themes, across the three sub-corpora. The key lexical items are extracted to reveal the details of the themes. A data table is constructed to record the presence or absence values of the lexical units versus the context units (such as sentences and paragraphs) in the sub-corpora. T-Lab then performs unsupervised clustering on the context units to uncover the thematic clusters of the three sub-corpora. Last, a chi-squared test is applied to all the intersections of the contingency table constructed by the lexical units and their corresponding clusters to test their statistical relationships.

D. Word Association: This method reveals how the co-occurrence relationships determine the local meaning of selected words, e.g., “nuclear power”. One can obtain the list of words that typically co-occur with the selected word in each sub-corpus to detect the difference across the sub-corpora. The co-occurrence strength is measured by the cosine index calculated based on the co-occurrences of the lexical units inside the context units in the sub-corpus.

2.2 Method 2: Review of China's Measures on Nuclear Safety

While statistical discourse analysis can decipher China's response to nuclear safety via carefully analzying the newspaper texts statistically, an in-depth comprehensive assessment of the institutional and technical performance of NPPs in China is necessary to verify whether China's promises on nuclear safety have been put into actions. A thorough qualitative review was conducted based on publicly available technical, policy and scientific information from credential international and local sources. They cover (1) the key official documents available on websites, key international references and peer-reviewed journal papers, and (2) the engineering/technical data indicative of the safety design and operation of NPPs in China obtainable from international nuclear organizations and research institutes, and the local nuclear power companies. Though the data does not include personal interviews with government officials, the solid comprehensive technical assessment will provide important insights on China's response to nuclear safety.

The first source of publicly available information is the set of key official documents released by China's National Nuclear Safety Administration (NNSA), consisting of technical reviews of both China's nuclear safety development and policy plans. In June 2012, the NNSA released the drafts of the Twelfth Five-Year Plan and the 2020 Vision of Nuclear Safety and Radioactive Pollution Prevention, and the Comprehensive Safety Inspection Report on Civilian Nuclear Facilities for public consultation. The inspection report concluded that the safety risks of NPPs in China were under control, but at the same time highlighted several areas that needed improvements in the short (by the end of 2012), medium (by the end of 2013) and long term (by 2015). These improvements cover flood resistance, emergency water supplies, mobile power supplies, spent fuel pool monitoring, emergency operating facilities, and the monitoring of radiation and the environment [34].

Policies concerning nuclear safety in China were documented in three major nuclear-related policy plans approved by the State Council in October 2012:

- The Twelfth Five-Year Plan and the 2020 Vision of Nuclear Safety and Radioactive Pollution Prevention (an amendment of the draft mentioned above) [35];

- The Nuclear Power Safety Plan (2011-20) [36]; and
- The Nuclear Power Mid- and Long-Term Development Plan (2011-20) [37].

The full texts of the two subsequent policy plans are not publicly available. Later in the same month (October 2012), a white paper, namely China's Energy Policy 2012, was published by the State Council. News releases and official materials presented by Chinese representatives in international conferences and journal papers are important supplementary information sources.

The second major document source comprises documents on China's nuclear safety performance and published by authoritative journals, key international nuclear organizations and China's nuclear power companies. Other materials include documents from the IAEA and the World Nuclear Association (WNA), figures relating to the size and the scale of China's latest nuclear power developments from the same source, plus the information obtainable from the websites of nuclear power companies in China. All these provide essential and reliable information to enhance the quality of comparison and evaluation on the safety design and operation of NPPs in China.

3. Results of Statistical Discourse Analysis

A longitudinal big-data/statistical discourse analysis was conducted to identify the concerns of the Chinese administration on nuclear energy in the wake of the Fukushima disaster. The findings are reported below.

A. Word Frequency

A list of high frequency content words appearing in the three sub-corpora was generated. Table 2 shows the top 20 words. If one examines the "safety" related words more closely, one can notice that these words undergo a dramatic change following the Fukushima disaster. Although the three sub-corpora are comparable in size (28,459 words, 41,882 words, and 44,803 words, respectively), "safety" related words increase notably in the first post-Fukushima sub-corpora by rank and by frequency (per 1000 words) (Table 3). It is noteworthy that this does not necessarily represent the actual change in safety measures in China, but possibly increasing awareness of nuclear safety by the authorities concerned.

Moreover, when examining the accident-related keywords ("accident" or "accidents"), we found that most of the accident-specific terms correlate with Chernobyl or Three Mile Island before the 2011 Fukushima nuclear accident. Only one accident-related keyword was identified in the context of a small leak from a fuel rod at the Daya Bay NPP in Shenzhen, China in June 2010. A senior official of the National Nuclear Safety Administration (NNSA) China asserted that the leak "cannot be called an accident and would do no harm to the external environment." [38] During the 2011-2014 post-Fukushima period, most accident-related keywords are related to the Fukushima nuclear accident, while some were used in the context of how the Chinese authorities will tackle the nuclear safety issues. During the 2014-2017 post-Fukushima period, the number of accident-related keywords that correlate with NPP accidents overseas (in particular, the Fukushima nuclear accident) is on the decline, as these accident-related keywords are more related to China's plans to cope with future accidents. One accident-related keyword is about the claim that China has a good safety track record during its NPP expansion, as no major accidents were observed in the period.

Table 2. High frequency content words

Sub-corpora	**High frequency content words (in descending order of frequency)**
A. Pre-Fukushima	nuclear, nuclear power, technology, plant, country, reactor, year, project, energy, construction, capacity, power, percent, build, province, development, company, plan, billion, start
B. Post-Fukushima 2011-2014	nuclear, nuclear power, energy, country, plant, Japan, safety, project, reactor, technology, plan, year, Chinese, construction, security, Fukushima, international, development, industry, world
C. Post-Fukushima 2014-2017	nuclear, nuclear power, energy, project, country, technology, plant, security, Chinese, company, build, year, construction, reactor, billion, plan, power, industry, Corp., China General Nuclear Power Group (CGN)

Table 3. Rank and frequency of "safety"-related words in the three sub-corpora

Terms	**Pre-Fukushima (2008-2011)**			**Post-Fukushima (2011-2014)**			**Post-Fukushima (2014-2017)**		
	Rank	**Raw Freq.**	**Freq. per**	**Rank**	**Raw Freq.**	**Freq. per**	**Rank**	**Raw Freq.**	**Freq. per**

			1000 words			1000 words			1000 words
"safety"	99	36	1.26	18	227	5.42	43	106	2.37
"inspection"	913	4	0.14	482	11	0.26	1500	3	0.07
"inspections"	N/A	0	0.00	405	14	0.33	1798	2	0.04
"standard"	1430	2	0.07	798	7	0.17	944	6	0.13
"standards"	664	6	0.21	180	28	0.67	190	28	0.62
"accident"	403	10	0.35	113	40	0.96	448	13	0.29
"accidents"	N/A	0	0.00	426	13	0.31	314	19	0.42

B. Specificity Analysis

The difference between the sub-corpora is clear from the specificity analysis, as shown in Table 4. Issues related to nuclear energy in the pre-Fukushima corpus (2008-2011) are rather broad, ranging from nuclear development to nuclear weapon and international disarmament. In contrast, the post-Fukushima sub-corpora focusses more on nuclear safety and security, international cooperation and investment, especially with the UK. Nuclear safety and related terms of nuclear safety are more frequently found in post-Fukushima sub-corpus (2011-2014), as compared to two other sub-corpora (2008-2011, and 2014-2017) (see Table 4).

Table 4. Top 20 sub-corpus specific words/phrases (i.e., words/phrases whose frequency is much higher in the specified sub-corpus than other sub-corpora (in descending order))

Sub-corpus	Words/phrases that are more specific in the sub-corpus
Pre-Fukushima sub-corpus (2008-2011)	Democratic People's Republic of Korea (DPRK), Guangdong, Xiang, State Nuclear Power Technology Corporation (SNPTC), Million Watt (MW), phase, capacity, yesterday, Qinshan, Six-Party, disarmament, nuclear power, million, weapon, America, generate, percent, total, Zhejiang, Sanmen

Post-Fukushima sub-corpus (2011-2014)	Japan, Fukushima, safety, earthquake, Tsunami, Iran, March, Japanese, crisis, nuclear safety, leader, Daiichi, Seoul, Taiwan, disaster, resume, inspection, leak, discharge, mechanism
Post-Fukushima sub-corpus (2014-2017)	China General Nuclear Power Group (CGN), Xi, EDF, Hinkley, UK, giant, export, nuclear, point, market, Britain, Corp., Africa, security, company, Argentina, pound, Chinese, competition, homegrown

C. Thematic Analysis

Eight different thematic models (ranging from three to ten themes) were generated by T-Lab for each sub-corpus. Based on our inspection, the four-theme model produces the most coherent themes and has therefore been selected. The themes and keywords are shown in Figures 3-5. One theme stands out across the three sub-corpora: the capacity of and investment in domestic nuclear energy-based projects. This suggests that China consistently viewed nuclear energy as an important part of its national energy strategy even after the Fukushima crisis. However, a couple of changes are noted in the post-Fukushima discourse. Before Fukushima, nuclear security (representing 36.0% of the context units in the pre-Fukushima sub-corpus), rather than nuclear safety, is the major concern (see Theme #A2, Figure 3). In the post-Fukushima sub-corpus (2011-2014), Fukushima crisis/nuclear safety penetrates the discourse of nuclear security to become an important topic (together representing 26.7% of the context units in the post-Fukushima sub-corpus (2011-2014), see Theme #B1, Figure 4). Nuclear power plant construction remains a major theme (representing 33.7% of the context units in the post-Fukushima sub-corpus (2011-2014), see Theme #B2, Figure 4), which probably indicates China's resolve to build more nuclear units during the early years after the Fukushima crisis. Across the second post-Fukushima sub-corpus (2014-2017), nuclear emergency response replaces nuclear safety to become a dominant theme (representing 19.7% of the context units in the post-Fukushima sub-corpus (2014-2017), see Theme #C3, Figure 5). Interestingly, the discourse of nuclear energy in China has increasingly intertwined with overseas nuclear investments, e.g., building new NPPs at Hinkley Point C in the UK during the post-Fukushima (2014-2017) period (see Theme#C2, Figure 5).

Four-theme model generated from the pre-Fukushima sub-corpus (2008-2011)

Theme #A1: Nuclear Reactor Technology (15.4% of the sub-corpus) Ten characteristic words: generation, supply, company, build, venture, technology, import, compare, analyst, third Top characteristic text samples for the theme: 1. China is building a total of six third-generation nuclear reactors in the country. Besides the four Westinghouse reactors, the country has also signed an agreement with the French nuclear power company Areva to use the company's third generation technology to build two reactors in Taishan in Guangdong province. 2. Last year China set up the State Nuclear Power Technology Corp Ltd, which is mainly responsible for domestic development of nuclear power using advanced third generation technology from overseas. Last July, China and a consortium led by the US-based Westinghouse Electric Co finalized a contract to build four third generation nuclear power reactors.	**Theme #A2: Nuclear Security (36.0% of the sub-corpus)** Ten characteristic words: nuclear, Democratic People's Republic of Korea (DPRK), weapon, security, talk, issue, Iran, international, disarmament, test Top characteristic text samples for the theme: 1. China calls for more nuclear reductions UN conference expected to seek nuke-free zone in Middle East NEW YORK – China on Tuesday encouraged the United States and Russia to further reduce their nuclear arsenals and reiterated its support for peaceful and diplomatic solutions to regional nuclear issues such as in Iran and the Democratic People's Republic of Korea. 2. As a world nuclear power, China has made unremitting efforts toward global nuclear disarmament. But the country's commitment of not being the first to use nuclear weapons has not led other members in the "Nuclear Club" to follow suit or pushed them to take a more rational and self-restrained approach toward developing nuclear weapons.
Theme #A3: Nuclear Plant Projects (22.6% of the sub-corpus) Ten characteristic words: project, Wang, city, Hunan, Hubei, Jiangxi, inland, nuclear plant, area, Shenzhen Top characteristic text samples for the theme: 1. As well as building nuclear projects in the coastal areas, China has also started developing them at inland sites. Three areas, in Hubei, Hunan and Jiangxi provinces, have been chosen as the first batch of inland nuclear projects. 2. The Taishan Clean Energy (Nuclear Power) Equipment Industrial Park that opened in February is expected to become one of the nation's centers for nuclear power equipment manufacturing, initially supplying hardware and services to nearby nuclear power projects.	**Theme #A4: Nuclear Power Capacity (26.0% of the sub-corpus)** Ten characteristic words: capacity, unit, total, million, reactor, install, generate, phase, percent, Zhejiang Top characteristic text samples for the theme: 1. According to an industry plan drawn up by the National Development and Reform Commission, China plans to increase its nuclear power capacity to 40 GW by 2020, accounting for 4 percent of the nation's total power capacity. However, in line with the rapid development of the sector, the target was reportedly revised to 70 GW. 2. Construction on the facility began in 1985. The first phase featured a 300,000-kW prototype reactor with a lifespan of 30 years, which went online in 1991. The first phase has so far generated 31 billion kWh of electricity and produced 9.6 billion yuan (US $ 1.28 billion) in revenue. China's nuclear power installed capacity is expected to reach 40 million kW by 2020.

Figure 3. Four-theme model generated from the pre-Fukushima sub-corpus (2008-2011)

Four-theme model generated from the post-Fukushima sub-corpus (2011-2014)

Theme #B1: Nuclear Safety and Security (Fukushima Daiichi Nuclear Disaster) (26.7% of the sub-corpus) Ten characteristic words: Japan, security, Fukushima, summit, nuclear, earthquake, material, disaster, international, Daiichi Top characteristic text samples for the theme: 1. As world leaders meet for the 2012 Seoul Nuclear Security Summit it is encouraging to note that not only is the issue of nuclear security being discussed, but also its interface with nuclear safety, following the Fukushima Daiichi accident in Japan. 2. Operators of the Fukushima Daiichi nuclear power plant in Japan failed to implement international nuclear safety standards designed to mitigate damage caused by earthquakes and tsunamis, an International Atomic Energy Agency (IAEA) report said last week.	**Theme #B2: Nuclear Power Construction (33.7% of the sub-corpus)** Ten characteristic words: construction, project, nuclear power, plant, state, operation, province, reactor, safety, build Top characteristic text samples for the theme: 1. The Hongyanhe nuclear power station, the first nuclear power plant and largest energy project in Northeast China, started operation on Sunday afternoon. The plant's first unit went into operation at 3:09 pm, said Yang Xiaofeng, general manager of Liaoning Hongyanhe nuclear power Co Ltd. 2. The dome of a containment structure at Taishan nuclear power Station in south China's Guangdong Province is topped out yesterday. Construction will soon start under the dome. With two third-generation reactors under construction, the Taishan power plant is expected to be one of the world's largest nuclear power projects.
Theme #B3: Nuclear Power Capacity (20.4% of the sub-corpus) Ten characteristic words: capacity, percent, electricity, GW, Westinghouse, coal, target, technology, carrier, million Top characteristic text samples for the theme: 1. China set a target of nuclear power production capacity reaching 86 gigawatts (GW) in 2020, from the current 10.8 GW, and nuclear power is set to be increased to 5 percent of total energy output by 2020, up from 1 percent now. 2. Renewable energy sources, such as solar and wind are still in their infancy and, when used alone, are not realistic solutions to meet increasing demand because of their intermittent supply of electricity. Nuclear powered electricity as part of a stable and sustainable electricity supply and therefore the China nuclear industry has seen rapid growth in the recent years.	**Theme #B4: Nuclear Negotiation (Iran) (19.2% of the sub-corpus)** Ten characteristic words: Iran, talk, Iranian, agreement, negotiation, exchange, sanction, news, East, Middle Top characteristic text samples for the theme: 1. The sanctions on Iran largely limited Iran's oil exports to China in the past, and the possibility of Iran going to a regional war in the Middle East also prevents China from more economic cooperation in the region, Li said. 2. Hopes have risen of a breakthrough preliminary deal in talks on Iran's nuclear program, observers said, as the second round of negotiations within a month between Iran and the world's major powers began on Wednesday.

Figure 4. Four-theme model generated from the post-Fukushima sub-corpus (2011-2014)

Four-theme model generated from the post-Fukushima sub-corpus (2014-2017)

Theme #C1: Nuclear Power Capacity (33.7% of the sub-corpus) Ten characteristic words: unit, construction, plant, province, capacity, nuclear reactor, reactor, nuclear power, install, total Top characteristic text samples for the theme: 1. These include Unit 1 at the Sanmen nuclear power plant in Zhejiang province, Unit 4 at the Fuqing plant in Fujian province, Unit 4 at the Yangjiang nuclear power plant in Guangdong province and Unit 1 of the Taishan plant in Guangdong, adding 6 GW of nuclear power capacity. 2. As of the end of October 2015, in Chinese mainland 27 nuclear generating units had been in operation, with a total installed capacity of 25.5 GW, and another 25 nuclear generating units with a total installed capacity of 27.51 GW had been under construction.	**Theme #C2: Overseas Nuclear Investment (UK) (29.2% of the sub-corpus)** Ten characteristic words: company, China General Nuclear Power Group (CGN), EDF, Crop., Chinese, UK, Hinkley, investment, agreement, project Top characteristic text samples for the theme: 1. Chinese and French companies signed the agreement to build an 18 billion pound (US $21.9 billion) nuclear power plant at Hinkley Point C during Xi's state visit to Britain in October last year. The CGN-led Chinese consortium and French company EDF respectively take 33.5 percent and 66.5 percent stakes. 2. Chinese companies, led by China General nuclear power Corp., will hold 33. 5 percent of shares of Hinkley Point C facility on Britain's northern Somerset coast through an investment from its British company called General Nuclear International, according to a statement by CGN.
Theme #C3: Nuclear Emergency Response (19.7% of the sub-corpus) Ten characteristic words: emergency, safety, accident, Fukushima, nuclear safety, disaster, people, Japan, response, program Top characteristic text samples for the theme: 1. Q: How has nuclear energy developed after Fukushima Daiichi disaster? A: The Fukushima Daiichi accident was a typical beyond design basis accident. The designer never thought huge waves could be as high as 15 meters, which submerged the plant. After the accident, each country equipped with nuclear plant's launched a thorough probe of their systems and facilities. 2. They will be tasked to support operators of nuclear facilities to handle contingencies, such as cordoning the radioactive source in nuclear accidents, rescuing trapped people, controlling the spread of contamination and minimizing the damage, said Yao, also deputy head of a national nuclear emergency response office.	**Theme #C4: Nuclear Security (International Cooperation) (17.4% of the sub-corpus)** Ten characteristic words: security, summit, Xi, international, G7, minster, material, global, terrorism, community Top characteristic text samples for the theme: 1. President Xi Jinping says China will continue to strengthen its nuclear security capability and remains firmly committed to building an international nuclear security system and supporting global cooperation. 2. Chinese President Xi Jinping attended the fourth Nuclear Security Summit held in Washington, where he delivered a speech on Saturday promoting an enhanced international nuclear security system and better global nuclear security management.

Figure 5. Four-theme model generated from the post-Fukushima sub-corpus (2014-2017)

D. Word Association

The difference between the sub-corpora can be revealed by word association with the term, "nuclear power". In the pre-Fukushima sub-corpus (Table 5), "nuclear power" most often occurs in combination with technology development-related terms. After the disaster, in the first post-Fukushima sub-corpus (2011-2014), the same phrase is associated not only with subject of construction but also with issues concerning safety. However, in the second post-Fukushima sub-corpus (2014-2017), "nuclear power" tends to occur in conjunction with technology development-related terms, while accidents and safety are no longer strongly associated with "nuclear power" (Table 5).

Table 5. Top 20 words with a strong association with "nuclear power" (i.e., words frequently co-occurring with "nuclear power") (in descending order)

	Top 20 words most strongly associated with "nuclear power" (in descending order)
Pre-Fukushima sub-corpus (2008-2011)	plant, reactor, country, technology, build, industry, project, Guangdong, construction, development, energy, capacity, province, plan, station, third-generation, percent, Corp., year, total
Post-Fukushima sub-corpus (2011-2014)	plant, project, station, Fukushima, nuclear, energy, state, Japan, world, safety, reactor, plan, operation, construction, country, national, Crop., UK, province, year
Post-Fukushima sub-corpus (2014-2017)	plant, nuclear, Crop., station, technology, construction, unit, build, project, develop, company, capacity, plan, general, energy, state, country, province, install, world

To summarize, the statistical discourse analysis shows that the administration's concern over nuclear accidents and safety surged immediately in light of the Fukushima disaster, but the initial momentum observed during 2011-2014 was increasingly replaced by concerns related to nuclear emergency response after 2014. Despite these safety concerns, China continues to expand its NPP developments domestically, and invest in overseas NPP projects, as demonstrated by its recent involvement in collaborating with France in the development of Hinkley Point C NPP in the UK.

4. Nuclear Safety Performance and Governance in China

Results from Section 3 have demonstrated a general increase in the awareness of nuclear safety shortly after the Fukushima accident in China. Based on authoritative sources identified from IAEA, WNA, and other credible sources, the following section will assess whether China's response to nuclear safety is rhetoric or real with reference to actual improvements in nuclear safety in China.

4.1 Nuclear Safety Performance

4.1.1 Nuclear Power Plant Design

The design of NPPs is an important indicator of nuclear safety. Nuclear reactor design is classified by "generation", i.e., Gen I, II, II+ and III. Among many considerations, safety is key in nuclear model classification system. Building passive safety features is particularly important because they serve the safety net in case human errors have occurred, or auxiliary power is lost [39].

Gen I reactor refers to the early prototypes, research reactors, and non-commercial power producing reactors. Gen II reactor refers to the full-size commercial nuclear power reactors, which began to operate between 1970 and 1996. The majority of the over 350 NPPs in operation in the world are of Gen II. They reflect the ‘state of the art’, after the Three Mile Island (TMI) accident in the US, which had major implications on the safety of the predominant Light Water Reactor designs. China imported the established Gen II design from France and deployed the system at Daya Bay. The Gen II design forms the basis of many of the reactor systems currently being built in China. Gen II reactors carry limited passive safety design features and utilize active safety features involving electrical or mechanical operations. While these traditional active safety features can be initiated automatically, they may also be initiated by the operators [13].

Gen II+ is a category specific to China. It updates the M3 design (a Gen II design) built in Daya Bay in the 1990s [40]. The first of these was the CPR-1000 design with improved seismic resistance, an improved reactor vessel for longer life, a digital control system, and built-in safety protection and mitigation systems. These were enhanced in the upgrades of CPR-1000 [41]. The more recent ACPR-1000 and ACP-1000 designs (both were incorporated into the Hualong One design in 2014) aimed at being a wholly Chinese design with safety characteristics equivalent to the Gen III design [42]. Based on the safety regulatory standards set by the NNSA of China after the Fukushima nuclear accident, the safety measures of existing Gen II+ models has been improved substantially, including (1) adopting the defence-in-depth principle to tackle extreme external events (earthquake and floods) with technical improvements across different layers of the system (namely, waterproof plugging, power supply, hydrogen elimination, and emergency cooling), (2) improving severe accident management guidelines, (3) completing safety margin assessments (stress tests) on operating NPPs, (4) in-depth re-evaluation of the earthquake and tsunami risks to the NPPs, and (5) formulating emergency response plans [43].

Gen III reactors were designed in the 1980s and offered evolutionary improvements over earlier reactors. Generally, they have engineered safety systems against loss of coolant accidents, and improved digital control systems and ergonomically designed control rooms. These types of reactors have been operating since 1995 [39].

Gen III+ reactors were designed in the late 1990s to deal with residual low frequency but potentially high consequence risks such as external hazards, and to address whole core accidents. The EPR (European Pressurized Reactor) and AP1000 reactors belong to this category and were considered to be state of the art in terms of safety. They were purchased by China and were being built in Taishan (EPR) and Sanmen (AP1000) [13]. Recently constructed Gen III+ reactors in the West are generally considered to be safer than Gen II reactors due to their defence-in-depth safety design [44-46].

Chinese reactors are arguably up to date technologically because they were built mostly after 1990, utilizing state-of-the-art technology of the time, whereas the majority of reactors in the rest of the world were built prior to 1990, utilizing Gen II technology [39, 47, 48]. Currently, nine Gen II+ and two Gen III reactors are in operation in China. Nine Gen II+ and seven Gen III (five Gen III, two Gen III+) reactors are under construction (Table A1, Table A2 in Appendix).

China's commercial NPPs are subject to inspections by the World Association of Nuclear Operators (WANO) and the IAEA. Adopting international safety performance indicators, WANO inspections benchmark the safety performance of Chinese operators with international NPP operators [49] (see Section 4.2.2 for more details). The State Council Research Office has reported a 100-fold reduction in predicted core damage and major release frequencies for Gen III+ designs as compared to their Gen II counterparts [46] (see Section 4.1.3 for more details).

4.1.2 Compliance with the IAEA Standards

The IAEA is a collaborative organization and has set up a series of nuclear safety standards, including general and specific safety requirements [50] in order to share best practice for the use of nuclear power. The integrated safety requirements ensure the protection of people and the environment, both now and in the future. According to the "Safety Assessment for Facilities and Activities" [50], seven features were assessed, namely site characteristics, safety functions, possible radiation risks, radiation protection, engineering aspects, human factors, and long term safety. The IAEA safety assessment helps identify areas for improvement for management systems and emergency response. Figure 6 summarizes the areas for improvement for operating NPPs in China, based on the IAEA standards. Two particular major site characteristics of the nuclear plants, namely anti-flood and anti-earthquake design, and emergency response, are the areas where operating NPPs should be improved [51].

The IAEA Standards Criteria \ Nuclear Power Plants in China (with Reactor Generation and Type)		Daya Bay (II - M310)	Qinshan phase I (II - CNP300)	Qinshan phase II (II - CNP600)	Qinshan phase III (II - Candu6)	Tianwan (II - VVER1000)	Ling Ao phase I (II - M310)	LingAo phase II (II+ - CPR1000)	Ningde (II+ - CPR1000)	Hongyanhe (II+ - CPR1000)
Site Characteristics	Earthquake	a							b	c
	Tsunami	c					d	d		
	Flood		e	e	e					
	Other External Events	f	f	f	f	f				
Engineering Aspect	Facilities								g	g
Human Factor	Emergency Response & Management	h	k	i		h, i	i	i	j	j
Total Number of Areas to be Improved		4	3	3	2	2	2	2	3	3

Specific Notes according to the IAEA Standards

a. Need to conduct in-depth evaluation on the earthquake risk of Daya Bay Nuclear Power Plant, and complete necessary improvements.
b. For uncompleted emergency response control center, need to make appropriate planning to improve the seismic capacity.
c. Need to conduct more in-depth analysis of tsunami drills.
d. Need to enhance the capability of anti-tsunami for each NPP in the coastal areas of Guangdong.
e. Problem with the design basis of flood; need for flood protection enhancement.
f. Need to conduct probability risk assessment of external event.
g. For hydrogen removal facilities, program design and instrument selection has completed; need to conduct equipment qualification test.
h. Need to study response plan when multiple reactors simultaneously enter a state of emergency.
i. Need for emergency planning for non-specific non-severe accidents.
j. Need to install emergency response control center.
k. Need for more detailed safety management guidelines, emergency response planning and resource optimization.

Figure 6. Areas where operating nuclear power plants need to improve with specific notes, by the IAEA standards. Source: [51]

Firstly, the site characteristics of the NPPs require improvement. The Ningde and Hongyanhe sites have an increased risk of earthquake damage, since they are closer to the Circum-Pacific seismic belt, and their seismic capacity must be improved. Located in the coastal area of Guangdong, the Daya Bay and Ling Ao facilities undergoes in-depth earthquake risk assessment and evaluations of the impact of secondary incidents such as tsunami resulting from an earthquake are conducted on other sites. It is also possible that the anti-flood design of Qinshan may not withstand extreme storm surges occurring during the largest astronomical tides [51] (Appendix II, p. 6).

Secondly, nuclear safety is highly dependent on safety management, especially emergency response planning. Emergency response refers to the preparedness for and response to a nuclear or radiological emergency in any state. Its implementation is intended to minimize the consequences on people, properties and the environment in any nuclear or radiological emergency [50]. Most NPPs in operation in China are in need of improvement in emergency response. Daya Bay and Tianwan facilities lack a sound response plan in face of situations when multiple reactors enter a state of emergency simultaneously. The current contingency plans put forward by Tianwan and Ling Ao are incomplete in face of potentially severe accidents. Furthermore, the emergency response control centers of Qinshan phase II, Ningde and Hongyanhe are not yet complete. There are no severe accident management guidelines for Qinshan phase I, and optimization of resource allocation is needed to better meet the requirements of emergency response [51].

Further, a number of engineering and management issues deserve attention and improvement. These include: insufficient supplies of portable power supplies, movable pumps and corresponding interfaces to maintain safety related functions in the event of station blackout; a lack of robust guidelines for severe accident management; inadequate preparation for an integrated, coordinated, emergency response at multi-unit sites; weak monitoring and control of hydrogen explosions; weak nuclear safety related legislation and policies for all nuclear activities, such as radioactive waste management; and inflexible regulatory bodies with limited financial and human resources [49, 51].

4.1.3 Safety Performance

Table A3 shows that China has a strong track record in nuclear safety in terms of incidents per reactor [52] (see Appendix). All nuclear events that have occurred in China have been either Level 0 or 1 (low-level) incidents. Table A3 highlights the level of each nuclear incident that has occurred in China based on the INES, defined by the IAEA [53]. Levels 0 to 7 indicate the severity of nuclear accidents, ranging from anomalies to major accidents. Levels 1-3 are classified as "incidents" and Levels 4-7 as "accidents". Events without safety significance are taken as "Level 0" or "below scale" [54]. Events below Level 1 are generally taken less seriously; however, in some cases, they may set up a chain reaction, leading to more serious events. China has so far been free of severe nuclear accidents and enjoys a good safety record [55].

Table 6 also shows that China has a strong track record in Frequency of Core Damage (CDF) and Frequency of Large Release (LRF), the two key safety indicators of reactor design for benchmarking the safety performance of NPPs [56]. The strictest safety levels set by the NNSA are less than 1×10^{-4} per reactor year for CDF, and less than 1×10^{-5} per reactor year for LRF, for the existing reactors [57]; and less than 1×10^{-5} per reactor year for CDF, and less than 1×10^{-6} per reactor year for LRF, for the new reactors [49]. Table 6 shows that all operating reactors in China have attained LRF and CDF values well below the strictest limits set by the NNSA. Even though the statistics of LRF and CDF of some of the most recent reactor models are not publicly available, they should be in compliance with the latest NNSA standard set for new NPPs in China, which is more stringent than the contemporary international counterparts, and should be safer technically than the previous nuclear models operating in China.

Table 6. Frequency of Large Release (LRF) and Frequency of Core Damage (CDF) for major nuclear reactors under operation in China as compared to major international design standards
(a) Major design standards in China and US

Design Standard	US NRC Standard (old NPP) [58]	US NRC Standard (new NPP) [58]	China's NNSA Standard (old NPP) [57]	China's NNSA Standard (new NPP) [49]
CDF	$< 1.0\times10^{-4}$	$< 1.0\times10^{-4}$	$< 1.0\times10^{-4}$	$< 1.0\times10^{-5}$
LRF	$< 1.0\times10^{-5}$	$< 1.0\times10^{-6}$	$< 1.0\times10^{-5}$	$< 1.0\times10^{-6}$

(b) Major nuclear reactors under operation and construction in China (as of 2018)

Reactor Model	II - French M310 [59, 60]	II - CNP300 [60]	II - CNP600 [60, 61]	II - Candu6 [55]	II - VVER1000 [62]	II - French M310 [59, 60]	II+ - CPR1000 (M310) [59, 60]	II+ - CPR1000 [60, 63]
Units	Daya Bay	Qinshan phase I	Qinshan phase II,	Qinshan phase III	Tianwan	Ling Ao phase I	LingAo phase II	Ningde, Hongyanhe,
CDF	2.13×10^{-5}	$< 1 \times 10^{-4}$	2.42×10^{-5}	$< 1 \times 10^{-5}$	3.3×10^{-6}	1.94×10^{-5}	1.53×10^{-5}	1.3×10^{-5}
LRF	2.45×10^{-6}	$< 1 \times 10^{-5}$	$< 1 \times 10^{-5}$	$< 1 \times 10^{-6}$	6.4×10^{-8}	2.45×10^{-6}	1.94×10^{-6}	$< 1 \times 10^{-6}$

4.1.4 Speed and Scale of Nuclear Project Development

China has revealed ambitious plans to develop the largest nuclear generators in the world, with plans to increase its nuclear capacity to 58GWe by 2020, 150GWe by 2030, and >200GWe by 2050 [13]. This rate is comparable to the peak years of the French nuclear development, when 54 reactors were built in 14 years, and the US nuclear construction programmes were introduced in the 1980s [64]. China has been developing its own designs and importing designs from overseas: M310 and EPR reactor designs from France, the VVER-1000 from Russia, CANDU-6 from Canada and AP1000 from the US. Although China has chosen advanced available designs, they require specialist knowledge and facilities to maintain. The cost of investment and the scale of manpower required to manage and maintain both locally and overseas-designed models is onerous and high [13]. China has been working on a broad range of nuclear technologies to make itself independent of external suppliers and to become a leader in nuclear technology.

4.2 Nuclear Safety Governance

4.2.1 Governance Structure

The decision-making process for nuclear development and safety regulations involves multiple authorities across various organizations. The responsibilities of these authorities sometimes overlap, making their roles and interaction in the decision-making process difficult to understand and challenging for public monitoring. Moreover, the regulation of nuclear safety lacks the independent verification of safety assessments and the equipment for on-site monitoring is insufficient.

Prior to 2008, governance over the energy sector in China was distributed between more than ten administrative bodies [65]. The National Development and Reform Commission (NDRC) is the most important policymaking and regulatory authority in the energy sector. The NDRC is a macroeconomic management agency under China's State Council, the highest executive organization in the country. The National Energy Commission (NEC) and the National Energy Administration (NEA) were established in 2008 as part of a major reshuffling of Chinese bureaucracy. The NEC is an advisory and coordination body on energy policy, working directly under the State Council. The NEA replaced the former Energy Bureau under the NDRC and absorbed various official energy bodies at the same time. As the executive arm of the NEC, the NEA implements energy development plans and industrial policies, promotes institutional reform in the energy sector, and oversees the licensing of projects, among other duties [66]. The State

Council approved the restructuring plan of the NEA in June 2013 (the current structure of energy bureaucracy is illustrated in Figure 7 [66-69]). A new nuclear energy department was formed, which was seen as an indication of the enhanced role of nuclear power in China's future energy development plan.

Under the Ministry of Industry and Information Technology, the China Atomic Energy Agency (CAEA) is responsible for planning and managing the use of nuclear technologies, as well as promoting international cooperation [66-69]. Following the Fukushima crisis, the NNSA is now authorized to develop regulations and guidelines for nuclear safety, license and regulate nuclear facilities and materials, and draft emergency response plans. It is administered under the Ministry of Environment Protection (MEP) but reports to the State Council directly [34] (Figure 7).

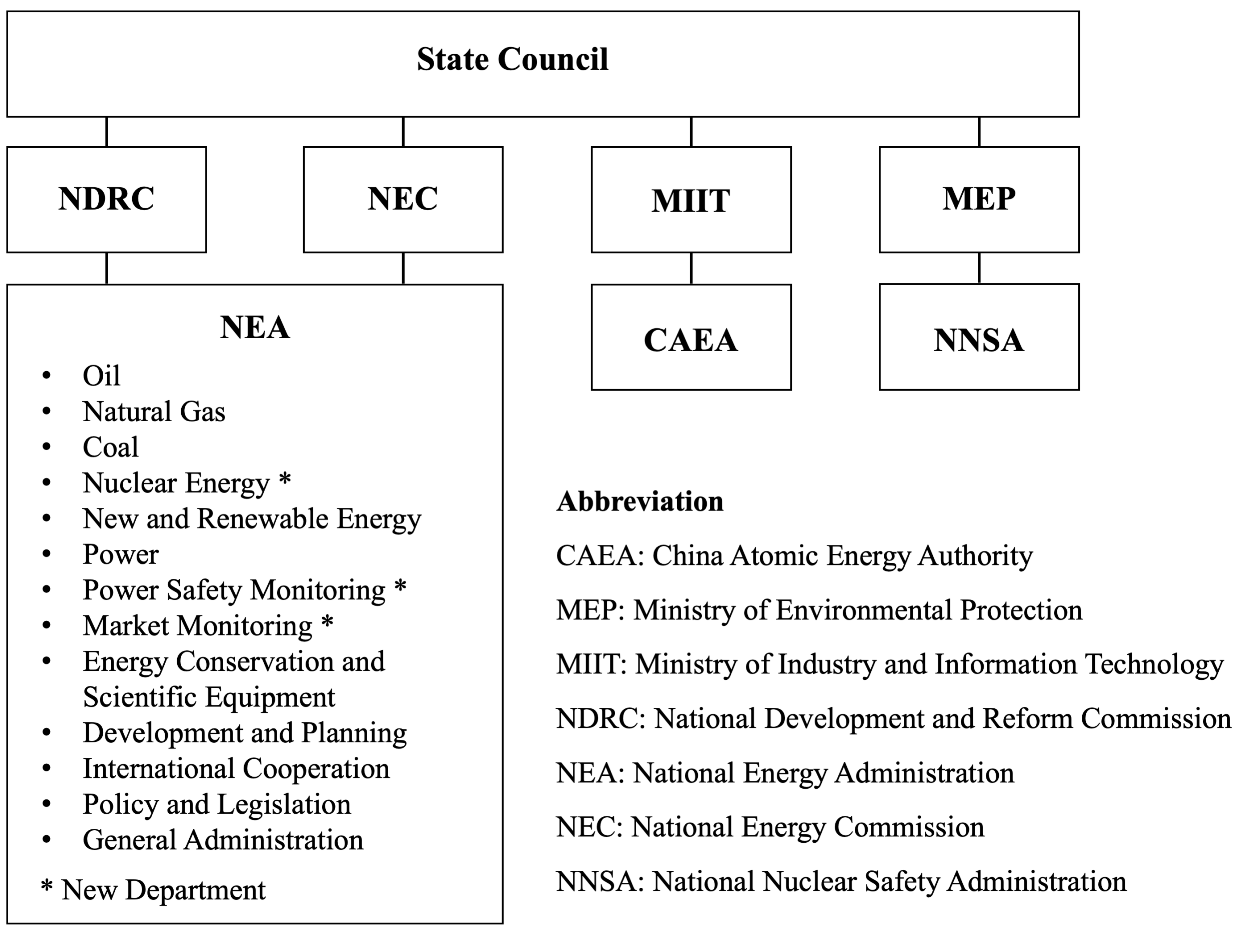

Figure 7. Key institutions involved in the nuclear safety regulatory governance in China. Source: [66-69]

Although the NNSA officially reports to the State Council directly, its place in the hierarchy may create ambiguities concerning the delegation and the implementation of safety responsibilities [68]. One issue raised by the Integrated Regulatory Review Service (IRRS) team was the implementation of legal responsibility for radiation protection of the occupational radiation workers [70]. The Chinese Basic Safety Standards are adopted as the mandatory standards by the "General Administration of Quality Supervision, Inspection and Quarantine," but are implemented by various government agencies and industries. No authority has been delegated the administrative or regulatory responsibility to enforce the requirements. In general, the rapid development of the nuclear power program in China has raised concerns for the need to strengthen the relevant regulatory framework in general. To address the fragmented administration and jurisdiction, the IRRS team highlighted the need for the regulatory system to be consolidated and for the NNSA to be appointed as the ultimate regulator.

4.2.2 Nuclear Safety Plans and Regulations

The Nuclear Power Mid- and Long-Term Development Plan (2005-2020) released in November 2007 laid down key principles asserting that nuclear power as a strategic energy source that should be actively pursued to meet the country's growing demand for energy sources [37, 71]. Shortly after the Fukushima crisis, in March 2011, the State Council announced that it would suspend approvals for the new NPPs and would perform comprehensive safety checks on both operating and under-construction NPPs [72]. Following this, a nine-month comprehensive safety review on nuclear power was undertaken by the Chinese administration [36]. To ensure nuclear safety, China has invited the Operational Safety Review Team (OSART) under the IAEA, the WANO and the China Nuclear Energy Association (CNEA) (with the Research Institute for Nuclear Power Operations, RINPO) to conduct external safety review for all NPPs, typically on a yearly basis [13]. China requested and hosted 12 OSART missions in October 2011 [13]. In May 2012, a new safety plan for nuclear power, the 12th Five-Year Nuclear Safety Plan and the 2020 Vision, was approved by the State Council in principle [35], reiterating that the country would put safety and quality first in nuclear power development [36]. At the same time, in an unprecedented move to improve the transparency of nuclear regulation, the administration also published the Comprehensive Safety Inspection Report about National Civilian Nuclear Facilities, and called for public inputs to the new nuclear safety plan [51]. The State Council formally approved two new nuclear safety plans in October 2012, namely, the Nuclear Power Safety Plan (2011-2020) and the Nuclear Power Mid- and Long-Term Development Plan (2011-2020) [36]. The list of plans and regulations on nuclear safety in China are highlighted in Table A4 in Appendix summarzing their contents.

4.2.3 Nuclear Safety Management

Safety management professionals are urgently needed, both to meet the growing demands for nuclear safety operation and regulation, and to support China's aggressive nuclear expansion [10]. International and national review of China's nuclear safety have highlighted the need to enhance the management of nuclear safety, by instilling a good safety culture and enlarging the professional workforce (Section 4.2.1). The IAEA defines a strong safety culture as "the assembly of characteristics and attitudes in organizations and individuals, … whereas protection and safety issues receive the attention warranted by their significance". The framework of safety culture consists of five components [73]:

1. Safety is a clearly recognized value;
2. Accountability for safety is clear;
3. Safety is learning-driven;
4. Leadership for safety is clear; and
5. Safety is integrated into all activities.

Building the required safety culture is a critical challenge for China. Although inspectors visit NPPs regularly to ensure that plant operations comply with guidelines and regulations, not all plant staff understand the significance of such precautions and safety has not established its position as a clearly recognized value among the staff of NPPs [66]. The NNSA has also recognized "the competency gaps in performing independent audit calculations as a part of safety assessment."[70] According to the IAEA's safety culture framework (especially the first component), this lack of recognition for safety may weaken a NPP's effectiveness in implementing proper safety measures [73].

A paucity of skilled nuclear engineers is presenting a challenge to the safety culture in NPPs. Although a number of employees from nuclear corporations have been sent to other countries for training or are trained in China by international experts (for example, some have received training offered by the Daya Bay facility) [74], this can hardly compensate for the lack of skilled engineers properly trained through tertiary education. By 2020, China would require more than 10,000 graduates majoring in nuclear engineering and science degrees, but enrolments in nuclear or related disciplines in universities have declined since the 1990s [74]. Increasing investments and collaborations in joint training programs with universities have been made by major nuclear corporations in China in response to the need for a future specialized workforce [66, 74].

Manpower shortages have not only affected the inspection of plant construction and daily operations, but also nuclear safety regulation [70]. The IRRS [70] has suggested that sufficient financial and human resources are to be channelled to the NPPs to maintain regulatory infrastructure, and recommended that specialized management programmes be set up to equip management experts with technical competence. By the end of 2018, the total number of registered nuclear safety engineers was 4,293, amongst whom 2,137 practised in 246 different companies [75]. Each registered nuclear safety engineer should possess 6 years of relevant work experience in addition to an undergraduate degree. For those with less than a 6-years of work experience, a higher degree is necessary for compensation [76]. The qualification requirement places less emphasis on work experience compared to other countries. In the UK, professionals working in regulatory agencies have to possess relevant qualification plus ten years' experience of nuclear safety in the industry. As of 2020, the total number of operating nuclear reactors in the US was 96 [77], while the US Nuclear Regulatory Commission (USNRC), the China NNSA's US counterpart, had about 2,880 employees [78]. According to USNRC, the ratio of regulatory staffing to nuclear reactors in the US should be no less than 40 [79]. Given that China had 45 operating reactors and 15 reactors under construction in 2018 and the NNSA's workforce was around 1,100 in 2020 [80], the number of regulatory staff per reactor was below the US level. To meet the increasing demand for nuclear capacity in China, the NNSA would have to enlarge its workforce to about 2.2 times of its current one to fully meet the NNSA's expectation on nuclear safety competence [70]. However, the regulator's hiring of safety inspectors in China is difficult because of the requirement for years of nuclear experience to be considered competent as a regulator and the increased competition for professionals from the utility companies and plant operators. In many countries, the requirement is ten years' industry experience following graduation from a master's program, and considerable time is required for the workforce to acquire the technical safety expertise.

4.2.4 Postponement of New Nuclear Projects Approval

After a temporary suspension of the construction of new NPPs in the aftermath of the Fukushima crisis, plans to build reactors resume. For nuclear new builds in China, though GIIIs are purchased from overseas, GII+ technologies, such as CPR1000 reactors, which are developed by China, will dominate the future nuclear market in China. Even though overseas GIII models such as EPR technologies are more popular options, GII+ models will take up a major share of the nuclear market in China due to the following reasons. First, AP1000 technology transfer is progressing slower than expected; Second, approval of AP1000s takes a long time to complete (at the moment, six inner-land units adopting AP1000s are yet to be approved); Third, GII projects carry a much better track record than their GIII counterparts in terms of equipment supply and site construction [81]. Hence, future nuclear projects are unlikely to abruptly shift from GII to GIII. Meanwhile, the NEA has tightened up its policy and introduced a comprehensive list of safety measures to enhance the safety performance of GII+ technologies in China, in order to significantly reduce the CDF and LRF, to the internationally recognized safety level equivalent of their GIII counterparts [13]. The tightening in safety measures means that it will take more time than originally expected for new nuclear reactors to be approved in China, even though the number of new nuclear reactors is not expected to decrease.

5. Discussion

This study analyses in depth China's concern over nuclear safety after Fukushima, using an interdisciplinary approach. Our study dissects nuclear safety in China using both social science and engineering approaches, deciphering attitudes towards nuclear safety within state-run Chinese newspapers, while analyzing both technical and policy documents on nuclear safety performance and governance in China. Our analysis aims to objectively address an important question: Is China's response to nuclear safety after Fukushima genuine or rhetoric?

5.1 Nuclear Safety in China: Genuine or Rhetoric?

The computational linguistic analysis shows that China's concern over nuclear safety surged dramatically in the wake of the Fukushima disaster. Apart from safety concerns, the development of and investment in nuclear energy remains prominent. On the whole, China has made significant efforts to improve nuclear safety performance and has maintained a good safety record in NPP design and operation. China has attempted to purchase or develop safer and more advanced Gen

II+ and Gen III technologies. All nuclear incidents occurred in China have been Level 0-1 incidents, based on the INES scale (see Table A3 in Appendix). All operating NPPs meet the NNSA thresholds, and some new nuclear reactors can achieve core damage and release frequencies well below the NNSA threshold. Most operating reactors are required by the NNSA to improve their site characteristics, safety management and emergency planning in some ways. In June 2021, a fuel failure was confirmed at Taishan NPP, even though "the proportion of damaged fuel rods is less than 0.01% of the total, which is much lower than the maximum damage of the fuel assembly assumed in the design proportion (0.25%)" while "there is no possibility of radioactivity leaking to the environment" [82].

Despite the strengths of NPP design and operation, some concerns remain. Sophisticated designs such as EPR Gen III+ reactors in Taishan have been modified and their safety is being called into question. Further, China has an ambitious plan to both grow its nuclear capacity at an unprecedented rate and develop a wide range of newer nuclear technologies in parallel. China has attempted to enhance nuclear safety governance by institutional restructuring and by providing more comprehensive safety plans and regulations, including inviting the internationally renowned safety authority, the IAEA, to conduct external safety reviews on its own NPP facilities post-Fukushima. However, the nuclear safety system appears to exhibit the following deficiencies:

1. Institutional fragmentation with responsibilities overlapping multiple bodies [68]
2. Eagerness to present a comprehensive and internationally recognized safety plan, but with an inadequate transparency for public scrutiny [83]
3. An insufficient number of well-trained, experienced nuclear inspectors and regulators to meet the increasing demand in China, and difficulties in fostering a robust safety culture in the short term [70]
4. Delays in approval of new nuclear projects in the short term, but with increasing number of new nuclear plans

Nuclear power is an unforgiving technology. It requires the application of high standards across all sectors of design, construction and operation. People and skills are crucial. How these people are trained, deployed and organized is also important. With the unprecedented rate and scale of nuclear development, the managerial challenges faced by the Chinese nuclear industry are huge. This poses a significant challenge, in terms of ensuring nuclear safety in China in the long run. We look forward to seeing how China will handle such a challenge and how nuclear safety in China can be ensured in a genuine sense in the future.

5.2 Areas for Improvement in China

The IAEA is the principle organization within the international community to have established an elaborate system to ensure nuclear safety around the world [74]. After the Fukushima accident, the IAEA published an action plan to strengthen the global nuclear safety framework [84], focusing on the following areas: safety standard and assessment, emergency preparedness and response, peer review, international legal framework, national regulatory body and operating organization, new NPP development, capacity building, radiation protection, information dissemination, and research and development. Based on the key focus proposed in this plan, areas for the improvement of nuclear safety in China are listed below:

5.2.1 Nuclear Safety Standards and Nuclear Reactor Technologies

While it is important to encourage China's transition to Gen III technologies, it is crucial to ensure that its own Gen II+ designs, such as the CPR1000+ and Gen III+ CAP1000, fully comply with international safety standards. China may also want to standardize nuclear reactor technologies among different nuclear utilities, paving the way for easier comparison of operations, identifying problems and solutions, developing standard training programs, establishing industry-wide best practices, and commercializing nuclear technologies beyond China.

5.2.2 Emergency Preparedness and Response

Because of the weak safety culture among NPPs in China and the fact that there has been no severe accident, emergency preparedness and response management has yet to receive appropriate attention. Some major nuclear facilities along the coastline require more adequate consideration of the probability of earthquakes or flooding. Emergency response planning undertaken by NPPs such as at Daya Bay have yet to address multiple nuclear accidents (Figure 6, Section 4.1.1, Section 4.1.2, Section 4.1.3). It is important for the Chinese authorities to require nuclear utilities at national and provincial levels to develop comprehensive nuclear safety management and emergency response plans, which should include independent third-party inspection and monitoring of nuclear safety plans and facilities on-site and off-site.

5.2.3 Regulatory System for Nuclear Safety Management

The institutional structure of nuclear safety management in China needs to be reviewed. In line with the recommendation of the NNSA [34], China should establish an independent regulatory unit delegated significant authority to manage nuclear safety. The IRRS [70] has suggested that sufficient financial and human resources should be channelled to the NPPs to maintain the regulatory infrastructure. The roles and responsibilities assigned to different departments regarding nuclear safety management should be clearly differentiated. The communication of an emergency response between nuclear safety authorities and different NPPs should also be clearly laid out. Whilst the national administration is in charge of overall emergency planning, local administration should be delegated with the responsibility of leading nuclear emergency responses (e.g., coordination of the authorities of health and environmental protection) and providing resource support in case of nuclear emergency. To reduce institutional fragmentation, it is important to set up a simple and effective institutional structure for nuclear safety management across all levels of governance. Clear roles and responsibilities should be assigned to individual units involved in nuclear safety management.

A culture of nuclear safety and the capacity of personnel needed for this cannot be developed overnight. However, a process-based risk-informed regulatory approach could provide the flexibility needed for China's safety regulation. The Fukushima disaster has demonstrated that accidents and extreme events that can critically impair nuclear power facilities may still occur. In the case of Fukushima, a catastrophic flood disabled all the power and cooling systems. These types of accidents were previously known as Beyond the Design basis Events (BDE). In pursuing the rapid growth of nuclear power projects both inland and offshore, China aims to take a pro-active and preventive approach to ensure that serious BDE accidents are prevented and mitigated effectively. This process-based approach focuses on the organizational systems that the facility has developed to assure the ongoing safety operation from the perspective of the facility's internal logic [85]. It recognizes that the design of organizational processes must remain flexible in order to allow the facility to create processes that are internally consistent, to adapt to their history and culture, and to allocate resources in the most rational way. Meanwhile, the risk-informed regulatory approach [86] can be adopted in parallel, to identify potential major nuclear accidents by providing an objective assessment of the probability of an accident together with its consequences. Subsequent actions can then be taken to mitigate all potential accidents.

5.2.4 Information Transparency and Public Participation

Transparency and public participation have been considered absolute conditions to reduce regulatory failure. Recently, China has attempted to increase transparency in nuclear safety governance by releasing new safety regulations and safety inspection reports. Radioactivity levels are regularly disclosed to the general public to increase transparency and for public monitoring [87]. Immediately following the Fukushima crisis, several regulations on nuclear communication were enacted, including the Program and Notice on Nuclear Safety Information Disclosure enacted by the MEP and the NNSA. Furthermore, nuclear safety information was disseminated throughout China by the environmental protection agencies to reduce public fears. Such moves are encouraging and will undoubtedly strengthen the public perception of nuclear safety of the NPPs, and boost public confidence and effectiveness in nuclear safety management [1]. Nevertheless, disclosure of information by the Chinese administration does not seem, at present, to have reduced public fear, though the Chinese administration remains the most trusted information provider [88]. Public participation in and access to information on nuclear construction and assessment remain marginal in China [88]. Important information, such as the national nuclear safety plan, has yet to be released to the public. To reduce public fears over major nuclear incidents in China, it is suggested that the Chinese administration continue building trust in its nuclear safety governance. Whilst China’s ongoing attempts to disclose the technical details of the safety report and environmental radioactivity to the public is admirable and can boost public trust, such trust can be strengthened should nuclear safety information with the public be clearly communicated further [89]. For instance, presenting safety information in layman’s terms to be readily understandable by the public would positively contribute to effective nuclear safety governance in the long run.

5.2.5 Capacity Building on Safety Personnel and Safety Culture

China has been making efforts to boost the workforce in nuclear industry to meet increasing demand for nuclear safety inspection and regulation, and to develop a nuclear safety culture (Section 4.2.1, Section 4.2.3). Administrative flexibility should be given to attract and retain suitably qualified and experienced regulatory staff. A regular rotation of resident inspectors is recommended to avoid regulatory capture. Also, in the absence of a well-developed safety culture, it is not entirely clear whether China would be able to introduce sweeping reform in nuclear safety management to optimise safety across the large number of new nuclear plants. With more sophisticated nuclear reactor technologies, and increased market demand, it is rather unlikely that there will be enough qualified nuclear local safety personnel to oversee safety design, construction, operation, maintenance and decommissioning in the short term. It is suggested that China may fill the gap of manpower shortage by recruiting qualified safety personnel from overseas and inviting overseas nuclear safety experts to provide safety training to local nuclear engineers. The IRRS report also noted that the initial training program for university graduates is not sufficiently comprehensive. The IRRS team suggested introducing a mentoring program beyond the initial certification program to help build inspectors' knowledge and skills, especially in areas that are not covered by procedures. This kind of proactive (as opposed to reactive) attitude is to be cultivated in order to maintain and improve safety systems.

5.2.6 International Collaboration

The nuclear reactors designed by China have incorporated overseas nuclear technology. China's Gen II+ technologies are based upon French M3 technologies, and China's Gen III+ utilizes the AP1000 reactor design from overseas. China may wish to continue working with overseas nuclear experts to conduct regular safety reviews and seek expert advice. Foreign experts can be invited to assess the design and performance of Chinese nuclear facilities that have integrated overseas technologies.

In real life, cultural differences between the Chinese and the Western world may shape the safety culture of individual civilizations. There are significant differences in staff-supervisor interaction between the East and the West. Chinese staff tend to use indirect methods to express their views in face of adverse events, to avoid being blamed [90]. Such cultural differences may shape the safety culture in the Chinese nuclear industry. In the UK, understanding the importance of employee vigilance and reporting is required for nuclear professionals of the Nuclear Institute [91]. In China, the culture of indirect reporting may affect nuclear safety. In face of accidents, workers in China may have cultural considerations when they have to decide whether to directly report to direct supervisors [92]. As safety culture cannot be developed overnight, China may wish to continuously collaborate with overseas countries and nuclear institutions in terms of nuclear safety training, and to start cultivating a safety culture that welcomes transparency and direct reporting of any problematic cases immediately, to strengthen its internal nuclear safety management capacity over the long run.

6. Conclusions

Our research raises the important question of whether China's response to nuclear safety following the Fukushima crisis is genuine or rhetoric. Our statistical analysis has demonstrated that nuclear safety and accidents have dominated the discourse news corpora of nuclear power in China immediately following Fukushima during 2011-2014, while nuclear emergency response has increasingly penetrated the same nuclear power discourse between 2014 and 2017. As the news media in China is a crucial channel for representing the state's policy direction and promotion, our findings reflect the state's significant concern over nuclear safety. These concerns have also been translated into policy measures, e.g., the re-examination of new NPP projects shortly after Fukushima. Regarding nuclear safety performance, China has paid serious attention to reactor technology safety design and operation. Safer and more advanced Gen II+/Gen III/Gen III+ technologies are being introduced and developed in China.

Our study was conducted based on two important sources: (a) the publicly available news media data that were widely accepted as representing the state views, and (b) credible and authoritative documents and websites that provide important safety information for in-depth assessment. Our two-way analysis has provided convincing evidence that China's priority on nuclear safety is beyond rhetoric. Nevertheless, various concerns remain. China's safety policy and governance is continuously impeded by its institutional fragmentation and overlapping, unclear roles and responsibilities for individual departments, inadequate public transparency, its lack of sufficiently experienced safety professionals, a weak safety culture, and an ambitious plan for a three-fold increase in nuclear capacity by 2040, and more beyond.

Though the nuclear industry in China remains highly sensitive, making it challenging to assess the nuclear safety information via face-to-face interviews, official peer review reports published by international nuclear organizations, such as the IAEA and WANO [13, 70], can provide independent third-party, trusted, and authoritative information to objectively review the technical and regulatory aspects of nuclear safety in China. Further, in terms of international cooperation on nuclear safety, China's nuclear regulator is in close contact with the IAEA to exchange and report nuclear safety-related information timely [49]. Given such close monitoring of China's nuclear operations and governance, the reviews of IAEA that we included in this study, should provide a reliable third-party assessment of the performance of nuclear safety in China. Based on our longitudinal quantitative discourse analysis, and in-depth comprehensive technical assessment from credible/official information sources, our current conclusions concerning whether China's response to nuclear safety is genuine, or rhetoric can be taken with confidence.

To ensure that nuclear safety continues to be a key priority in the long term, nuclear safety performance in China may require specific institutional, cultural and policy reform. We suggest the following actions to improve nuclear safety policy-makings in China, including: strengthening nuclear safety management and emergency response by means of independent third-party inspection, improving nuclear regulatory structure, adopting a precautionary approach towards risk-informed nuclear safety regulation, advocating information transparency and public participation, and championing the safety culture and international collaboration for capacity-building.

7. Limitations of the Study

It must be noted that no direct face-to-face interviews with the responsible nuclear safety bodies or the nuclear industry in China, with regard to their positions toward the current status of nuclear safety in China, have been conducted. However, this limitation can be compensated for by our two-way assessment, which allows us to track China's positions and response towards nuclear safety over an extended period of time from multiple credential/official sources, both locally and internationally. Such approach offers a comprehensive, and credible assessment of the current status of nuclear safety in China, instead of evaluating based on the views of a few individuals.

Even though our current assessment of nuclear safety designs and operations is based on the information publicly released by the local nuclear power companies, it is further complemented by credible scientific publications, as well as openly accessible and technical reports/policy papers published by China and international organizations, including the IAEA and the WNA. Potential inadequacies or discrepancies in this study can be compensated for by comparing and contrasting information from different official and authoritative sources inside and outside of China.

Declarations of interest: none

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Appendix

Table A1. Operable Nuclear reactors in China (as of 2018). Source: [13]

Units	**Province**	**Net capacity (each)**	**Type**	**Grid connection**	**Commercial operation**
Daya Bay 1&2	Guangdong	944 MWe	French M310		
Qinshan Phase I	Zhejiang	298 MWe	CNP-300	Dec 1991	April 1994
Qinshan Phase II, 1&2	Zhejiang	610 MWe	CNP-600	Feb 2002, Mar 2004	April 2002, May 2004
Qinshan Phase II, 3&4	Zhejiang	619, 610 MWe	CNP-600	Aug 2010, Nov 2011	Oct 2010, Dec 2011
Qinshan Phase III, 1&2	Zhejiang	677 MWe	Candu 6 PHWR	Nov 2002, June 2003	Dec 2002, July 2003
Fangjiashan 1&2	Zhejiang	1012 MWe	CPR-1000 (M310+)	Nov 2014, Jan 2015	Dec 2014, Feb 2015
Ling Ao Phase I, 1&2	Guangdong	950 MWe	French M310	Feb 2002, Sept 2002	May 2002, Jan 2003
Ling Dong/Ling Ao Phase II, 1&2	Guangdong	1007 MWe	CPR-1000 (M310)	July 2010, May 2011	Sept 2010, Aug 2011
Tianwan 1&2	Jiangsu	990 MWe	VVER-1000/V-428	May 2006, May 2007	May 2007, Aug 2007
Tianwan 3&4	Jiangsu	1060 MWe	VVER-1000/V-428M	Dec 2017, Oct 2018	Feb 2018, Dec 2018
Ningde 1&2	Fujian	1018 MWe	CPR-1000	Dec 2012, Jan 2014	April 2013, May 2014
Ningde 3&4	Fujian	1018 MWe	CPR-1000	Mar 2015, Mar 2016	June 2015, July 2016
Hongyanhe 1&2	Liaoning	1061 MWe	CPR-1000	Feb 2013, Nov 2013	June 2013, May 2014

Units	Province	Net capacity (each)	Type	Grid connection	Commercial operation
Hongyanhe 3&4	Liaoning	1061 MWe	CPR-1000	Mar 2015, April 2016	Aug 2015, Sept 2016
Yangjiang 1&2	Guangdong	1000 MWe	CPR-1000	Dec 2013, Mar 2015	March 2014, June 2015
Yangjiang 3&4	Guangdong	1000 MWe	CPR-1000+	Oct 2015, Jan 2017	Jan 2016, Mar 2017
Yangjiang 5	Guangdong	1000 MWe	ACPR1000	May 2018	July 2018
Fuqing 1&2	Fujian	1020 MWe	CPR-1000 (M310+)	Aug 2014, Aug 2015	Nov 2014, Oct 2015
Fuqing 3&4	Fujian	1000 MWe	CPR-1000 (M310+)	Sept 2016, July 2017	Oct 2016, Sept 2017
Fangchenggang 1&2	Guanxi	1000 MWe	CPR-1000	Oct 2015, July 2016	Jan 2016, Oct 2016
Changjiang 1&2	Hainan	601 MWe	CNP-600	Nov 2015, June 2016	Dec 2015, Aug 2016
Taishan 1	Guangdong	1660 MWe	EPR	June 2018	Dec 2018
Sanmen 1&2	Zhejiang	1157 MWe	AP1000	June 2018, Aug 2018	Sept 2018, Nov 2018
Haiyang 1&2	Shandong	1170 MWe	AP1000	Aug 2018, Oct 2018	Oct 2018, Jan 2019

Table A2. Nuclear reactors under construction or planned in China (as of 2018). Source: [13]

Under construction

Units	Province	MWe gross	Reactor model	Construction start	Expected grid connection
Taishan unit 2	Guangdong	1750	EPR	4/10	2019
Shandong Shidaowan	Shandong	211	HTR-PM	12/12	2019
Yangjiang unit 6	Guangdong	1086	ACPR1000	12/13	2019
Hongyanhe units 5&6	Liaoning	2x1119	ACPR1000	3/15, 7/15	2019, 2020
Fuqing units 5&6	Fujian	2x1150	Hualong 1	5/15, 12/15	2019, 2020
Fangchenggang units 3&4	Guangxi	2x1180	Hualong 1	12/15, 12/16	2019, 2020
Tianwan units 5&6	Jiangsu	2x1118	ACPR1000	12/15, 9/16	2020, 2021
Xiapu unit 1	Fujian	600	CFR600	12/17	2023
Bohai shipyard FNPP	Liaoning	60	ACPR50S	11/16	2020

Planned

Units	Province	MWe gross	Reactor model	Expected construction start from
Shidaowan/Rongcheng units 1&2	Shandong	2x1400	CAP1400	2019
Xudabao units 1&2	Liaoning	2x1250	CAP1000	2019
Xudabao units 3&4	Liaoning	2 x 1200	VVER-1200/V-491	

Units	Province	MWe gross	Reactor model	Expected construction start from
Haiyang units 3&4	Shandong	2x1250	CAP1000	
Lufeng (Shanwei) units 1&2	Guangdong	2x1250	CAP1000	
Sanmen units 3&4	Zhejiang	2x1250	CAP1000	2019
Ningde units 5&6	Fujian	2x1150	Hualong 1	
Zhangzhou units 1&2	Fujian	2x1150	Hualong 1	2019
Tianwan 7&8	Jiangsu	2x1200	VVER-1200/V-491	2021
Huizhou/Taipingling units 1&2	Guangdong	2x1150	Hualong 1	2019
Lianjiang units 1&2	Guangdong	2x1250	CAP1000	
Haixing units 1&2	Hebei	2x1250	CAP1000	
Fangchenggang units 5&6	Guangxi	2x1150	Hualong 1	
Bailong units 1&2	Guangxi	2x1250	CAP1000	
Changjiang SMR units 1&2	Hainan	2x100	ACP100	
Taishan units 3&4	Guangdong	2x1750	EPR	
Changjiang units 3&4	Hainan	2x1150	Hualong 1	

Units	Province	MWe gross	Reactor model	Expected construction start from
Taohuajiang units 1-4	Hunan (inland)	4x1250	CAP1000	
Pengze units 1&2	Jiangxi (inland)	2x1250	CAP1000	
Xianning (Dafan) units 1&2	Hubei (inland)	2x1250	CAP1000	
Xiapu unit 2	Fujian	600	CFR600	

Table A3. No. of incidents of major operating nuclear reactors in China from 2009 to 2017 Source: [52]

<table>
<tr><th rowspan="2">Nuclear Power Plant</th><th rowspan="2">Starting Year</th><th colspan="2">2009</th><th colspan="2">2010</th><th colspan="2">2011</th><th colspan="2">2012</th><th colspan="2">2013</th><th colspan="2">2014</th><th colspan="2">2015</th><th colspan="2">2016</th><th colspan="2">2017</th></tr>
<tr><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th><th>Level 0</th><th>Level 1</th></tr>
<tr><td>Daya Bay unit 1</td><td>1994</td><td>2</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Daya Bay unit 2</td><td>1994</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Ling Ao unit 1</td><td>2002</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td rowspan="3">3</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">5</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td></tr>
<tr><td>Ling Ao unit 2</td><td>2003</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Ling Ao unit 3</td><td>2010</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>2</td><td>0</td><td>2</td><td>0</td><td>1</td><td>0</td></tr>
</table>

Ling Ao unit 4	Ningde unit 1	Hongyanhe unit 1	Qinshan units 1-5	Tianwan units 1-2	Fangjiashan	Fuqing units 1-2	Fuqing units 3-4	Yangjiang units 1-2	Yangjiang units 3-4
2011	2013	2013	1991	2007	2015	2015	Sep 2017	2015	2017
NA	NA	NA	2	3	NA	NA	NA	NA	NA
NA	NA	NA	0	1	NA	NA	NA	NA	NA
NA	NA	NA	5	2	NA	NA	NA	NA	NA
NA	NA	NA	1	0	NA	NA	NA	NA	NA
7	NA	NA	10	1	NA	NA	NA	NA	NA
0	NA	NA	0	0	NA	NA	NA	NA	NA
2	NA	NA	5	2	NA	NA	NA	NA	NA
0	NA	NA	0	0	NA	NA	NA	NA	NA
1	10	12	5	1	NA	NA	NA	NA	NA
0	0	0	0	0	NA	NA	NA	NA	NA
	9	5	1	0	NA	NA	NA	NA	NA
	0	0	0	0	NA	NA	NA	NA	NA
	7	3	7	2	2	11	NA	3	2
	0	0	0	0	0	0	NA	0	0
	21	6	1	2	3	5	NA	7	
	0	0	0	0	0	0	NA	1	
	7	2	5	3	2	4	5	7	
	0	0	0	0	0	0	0	0	

Changjiang units 1-2	2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2	0	10	0	3	0
Fangchenggang	2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	0	9	0	2	0

Table A4. List of nuclear safety plans and regulations in China

Plan/Regulation	**Date Issued**	**Issuing Authority**	**Main Contents**
Nuclear Power Mid- and Long-Term Development Plan (2005-2020)	November 2007	NDRC	(1) Polices for nuclear technology innovation, legal framework, talent training, investment incentives, and nuclear fuel security; (2) By 2020, the target installed capacity for in-operation NPPs and under-construction NPPs is 40GWe and 18GWe, respectively.
State Council Executive Meeting	March 2011	State Council	(1) Suspend approvals for new NPPs; (2) Perform comprehensive safety checks on both existing and under-construction NPPs; (3) Improve safety management on in-operation NPPs.
12th Five-Year Nuclear Safety Plan and the 2020 Vision	May 2012	State Council	(1) Improve the ability to prevent and mitigate serious nuclear accidents; (2) Strengthen nuclear technology and application; (3) Improve

			nuclear emergency response system; (4) Enhance regulatory capacity by independent evaluation, public transparency and international collaboration.
Nuclear Power Safety Plan (2011-2020) Nuclear Power Mid- and Long-Term Development Plan (2011-2020)	October 2012	State Council	(1) Resume NPP construction; (2) Arrange a few fully demonstrated coastal sites during the 12th Five-Year period and exclude inland sites; (3) Develop new NPPs with safety standards at least equivalent to Gen III; (4) By 2020, the target installed capacity for in-operation NPPs and under-construction NPPs is 58GWe and 30GWe, respectively.