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China's Response to Nuclear Safety Post-Fukushima: Genuine or Rhetoric?

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Abstract The Fukushima crisis has brought the nuclear safety problem to the world's attention. China is the most ambitious country in the world in nuclear power development. How China perceives and responds to nuclear safety issues carries significant implications on its citizens' safety and security. This paper examines the Chinese government's promised and actual response to nuclear safety following the Fukushima crisis, based on (1) statistical analysis of newspaper coverage on nuclear energy, and (2) review of nuclear safety performance and safety governance. Our analysis shows that (i) the Chinese government's concern over nuclear accidents and safety has surged significantly after Fukushima, (ii) China has displayed strengths in reactor technology design and safety operation, and (iii) China's safety governance has been continuously challenged by institutional fragmentation, inadequate transparency, inadequate safety professionals, weak safety culture, and ambition to increase nuclear capacity by three-fold by 2050. We suggest that China should improve its nuclear safety standards, as well as safety management and monitoring, reform institutional arrangements to reduce fragmentation, improve information transparency, and public trust and participation, strengthen the safety culture, introduce process-based safety regulations, and promote international collaboration to ensure that China's response to nuclear safety can be fully implemented in real-life.

Keywords nuclear safety, media focus, computational text analysis, regulatory governance, safety management

JEL Classification C89, Q42, Q48

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China's Response to Nuclear Safety Post-Fukushima: Genuine or Rhetoric?

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1. Introduction

After Japan's Fukushima disaster, nuclear energy safety is re-catching the world's attention. The Fukushima accident that resulted in the melt-down of three reactor cores was rated by International Atomic Energy Agency (IAEA) as Level 7 incident, the highest level on the International Nuclear and Radiological Event Scale (INES) [1]. After the Fukushima accident, anti-nuclear sentiment

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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 has surged markedly in many countries [2-4]. The vulnerability of nuclear power plants (NPPs) worldwide has been called into question [5]. The desire for continual dependence on nuclear energy as a clean, reliable and affordable electricity source is overridden by the populist anti-nuclear sentiment. Some countries have decided to immediately shut down nuclear reactors or gave up on plans for new plants [6] but others, such as Germany, has planned to close all of its NPPs by 2022; Some countries such as the UK, has recommitted to building new reactors to replace old ones. Whilst nuclear energy is expected to grow slowly in many developed countries [7], developing countries have been reliant on nuclear power due to energy security and environmental constraints, and a radical shift in nuclear policy was considered unlikely [8, 9].

There are three reasons why the study of nuclear safety in China is a key priority. First, China has become the most ambitious country in the world in nuclear power development [10-12] (Figure 1). By 2013, Nuclear power makes up only 2% of China's total electricity generation. However, the projected share of nuclear power will increase dramatically to 7% of total electricity generation by 2040 [13]. As of 2017, the share of nuclear is increased up to 4% of total electricity generation [14]. As of 2018, China has about 45 nuclear power reactors in operation, 15 under construction, and many more about to be constructed [14]. By 2014, three years after Fukushima, China was planning to build 72 reactors, amongst which 20 are in operation, 28 under construction, and 24 are being planned [15, 16] (Table 1, Table 2, and Figure 2). Nuclear power plans during this period reflect the Chinese sentiment towards the use of nuclear power. The nuclear facilities under construction will tremendously increase the existing nuclear capacity, giving a minimum of 58GWe by 2020, 150GWe by 2030, and more than 200GWe by 2050 [16]. This massive and rapid development of NPPs in China can potentially put nuclear safety at risk. China has been highly dependent on design and knowledge imported from France, the US and Canada. China's fast nuclear power expansion thus raises a question: Will the progress in nuclear safety and safety culture that China has achieved so far be counter-balanced by the rising in nuclear capacity, and the associated challenges of nuclear design, construction, operation and maintenance, and planning for decommissioning? Second, it is uncertain whether China's current institutional arrangement that oversees nuclear safety regulations, guidelines, and procedures, can provide an effective safety mechanism for such a mega project and prevent catastrophic nuclear accidents. Third, there are ongoing concerns about whether China's NPP can meet the IAEA safety standards.

With a population of 1.3 billion, how China perceives and responds to the nuclear safety carries significant implications for the safety and security of its people. This paper explores three key questions. First, what is the Chinese government's view of nuclear safety following the Fukushima crisis? Second, what are China's actual responses to nuclear safety? Third, are these responses genuine or rhetoric?

Our analysis takes the following form. The first section will cover the statistical discourse analysis. The approach is applied to a large quantity of news media texts to identify viewpoints over nuclear safety [17, 18]. The approach serves as an alternative means to deciphering the government's concern over sensitive issues in circumstances where obtaining relatively objective data via interviews or official documents is rather difficult. The second section investigates the actual safety performance and the governance of NPPs in China through safety performance and policy analysis. Finally, we will assess whether China's response to nuclear safety is genuine or simply rhetoric, and propose areas for policy intervention and improvement.

2. Methodology

2.1 Statistical Discourse Analysis

Traditionally, to understand the government's concern about nuclear safety is to conduct a qualitative analysis based on interviews and government documents. Whilst these approaches are valuable, the task has become increasingly daunting as researchers are required to handle a huge quantity of available information. In contrast, statistical text analysis delivers a "systematic, objective, quantitative analysis of message characteristics" [19], and has become a useful methodology to complement qualitative analysis in domains such as policy studies [20] and media studies [21]. In China, state-run newspapers are the few key channels through which government viewpoints regarding certain policy issues are expressed and shared with the public [22, 23]. Systematic tracking of news reports over time could minimize potential bias of individual documents or interviewees. Such analysis would help reveal the change in concerns over nuclear safety before and after the Fukushima disaster.

Newspaper texts are used in this study for several reasons. Government documents are not always publicly accessible and tend to be prescriptive. Moreover, official documents generally take longer to draft and publish, and may not capture the dynamic socio-political changes in a timely manner. Newspaper reports permit the continuous tracking of evolving events (e.g. the Fukushima disaster) on a daily basis. Lastly, media texts in China are indicative of up-to-date policy foci and direction [24]. Unlike the Western countries, news in China is administered by various government bodies; the primary newspaper in China, China Daily, is state-run and targets at facilitating official information dissemination and policy implementation. More than 80% of the newspapers coverage represents the views of the government than otherwise [25], the voices of the public remain largely dormant in Chinese newspapers in most cases.

Three English state-run newspapers are collected for this research. Despite a difference in readership between these three English state-run newspapers and the Chinese counterparts, the

English newspapers share similar functions as the Chinese counterpart, representing the viewpoint of the Chinese authority. It is therefore selected for the computational text mining study, as most readily available mining tools can produce far better and more reliable results when they work on the English instead of Chinese texts. The newspaper texts used herein were published in three major English newspapers in China – namely, China Daily, Shanghai Daily and Shenzhen Daily, from 11 March, 2008 to 11 March, 2013. China Daily is the first state-run national English newspaper in China, which is considered the English equivalence of the People's Daily. It is the most authoritative official newspaper and serves as the key mouthpiece of the Chinese Communist Party [26]. Shanghai Daily and Shenzhen Daily provide comprehensive news coverage at the regional level in China [27]. Most of the opinions covered by these three state-run English newspapers were quoted from the official sources [25]. The articles were retrieved from the news archive, Wisenews portal (URL: http://www.wisers.com/corpsite/global/en/home/index.html), using the query *("nuclear power" OR "nuclear energy") AND "China"*. The articles were verified manually to confirm their relevance. A total of 1,082 articles were collected, covering a five-year period. To compare the changes in attention over nuclear safety, the corpus is divided into (i) pre-Fukushima sub-corpus and (ii) post-Fukushima sub-corpus (the distribution of the articles across the five years can be found in Table 3).

The text mining software package T-Lab version 9.1 (URL: http://www.tlab.it) was used to perform four analyses, based on statistical analysis of word frequency and co-occurrence (see [28] re. the use of T-Lab for data mining). The advantage of using data mining for textual analysis is that the quantitative analysis is not based simply on word count. 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 the newspaper. T-Lab detects 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 to discount high frequency words that are of less information value.

A. High Frequency Word List: The most frequently occurring content words are extracted from each sub-corpus for preliminary comparison. They provide a preliminary indication of major issues discussed in the sub-corpora.

B. Specificity Analysis: This identifies the lexical units that are typical of or exclusive to a sub-corpus. The analysis highlights the different distribution of lexical items in the two sub-corpora. It shows how the discourse foci change across the two sub-corpora.

C. Thematic Analysis: This identifies potentially important themes (topics) in the two sub-corpora. Key lexical items are extracted to reveal the details of themes. First, a data table is constructed to measure the presence or absence value of words in units such as sentences and paragraphs. Based on this data table with TFIDF normalization, clustering is performed on the context units. Chi-square test is then applied to the intersections of the contingency table constructed by lexical units and their corresponding clusters. Last, correspondence analysis is conducted to identify the significant thematic clusters. Moreover, different combinations of themes can be generated for manual comparison to obtain the best characterization of the texts.

D. Word Association: This reveals how co-occurrence relationships determine the local meaning of selected words, e.g. “nuclear safety”. One can obtain the list of words that typically co-occur with the selected word in the sub-corpora. The co-occurrence strength is measured by statistical measures of co-occurrence.

2.2 Review of Chinese Government's Measures on Nuclear Safety

To identify the actual response of China towards nuclear safety, a thorough literature review has been conducted, covering a wide range of sources, including (1) key official documents made available via the website of the Chinese government, and also made available through up-to-date key international references and peer-reviewed journal papers; and (2) engineering data indicative of the safety design and operation of NPPs in China obtainable from international nuclear organizations and research institutes, and the nuclear power industry in China.

The first source is a set of key official documents from China's National Nuclear Safety Administration (NNSA) covering both a technical review of China's nuclear safety development and policy plans. In June 2012, NNSA released 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. This nationwide inspection took nine months to complete. The inspection report concluded that the safety risks of NPPs in China were under control, but at the same time identified several areas that needed improvement in the short (by the end of 2012), medium (by the end of 2013) and long terms (by 2015). These improvements covered technical requirements such as flood resistance, emergency water supplies, mobile power supplies, spent fuel pool monitoring, emergency operating facilities, and the monitoring of radiation and the environment [29].

The policy plans concerning nuclear safety in China were covered by 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) [30];
- The Nuclear Power Safety Plan (2011-20) [31]; and

- The Nuclear Power Mid- and Long-Term Development Plan (2011-20) [32].

Full texts of the latter two 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 became important supplementary information sources.

The second source is a set of documents focusing on China's nuclear safety performance, published by authoritative journals and key international nuclear organizations and China's nuclear power companies. These documents contain essential and substantial data that serve as the basis for an evaluation and comparison of the safety design and operation of NPPs in China, including documents from the IAEA, and the World Nuclear Association (WNA). Figures relating to the size and scale of China's latest nuclear power developments were also obtainable from the same source, in addition to the websites of nuclear power companies in China.

3. Results of Statistical Discourse Analysis

The statistical analysis is conducted to identify the concerns of the Chinese government 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 two sub-corpora has been generated and Table 4 shows the top 20 such words. The word lists are quite similar (Table 4). However, if one examines the "safety"-related words more closely, it can be seen that these words underwent a dramatic change following the Fukushima disaster. Although the sub-corpora are comparable in size (175,368 vs. 153,776 character tokens), the prominence of "safety"-related words increases notably in the post-Fukushima sub-corpus by rank and by frequency (Table 5).

B. Specificity Analysis

The difference between the sub-corpora is clear from the specificity analysis, as shown in Table 6. Issues related to nuclear energy in the pre-Fukushima corpus are rather broad, ranging from international relations, and military relations, to new energy. In contrast, the post-Fukushima corpus comprises many terms related to crisis and safety. Generally, the degree of disproportional distribution of words in the post-Fukushima corpus is much higher in the Chi-square Test (Table 6).

C. Thematic Analysis

Eight different thematic models (ranging from three to ten themes) are generated by T-Lab for each sub-corpus. The three-theme model produces the most coherent themes and is selected (the themes and keywords are given in Table 7 and Table 8). Figure 3 and Figure 4 also illustrate the relationship between the first two principal components (Factor 1 and Factor 2), which are derived from the contingency table via corresponding analysis and the row categories, i.e., the clusters (themes), or the column categories, i.e. the lemmas. Two factor scores of the theme points or the lemma points are shown on the X-axis and the Y-axis. Points on opposite sides of the component axis indicate that this component is in contrast with the corresponding categories. Smaller distances between the lemma points and a particular theme point suggest that the theme can be better characterized by these lemmas. Two themes figure equally prominently in the two sub-corpora, namely, international cooperation / development, and capacity of and investment in nuclear energy-based projects. This suggests that China still considers nuclear energy to be an important part of its national energy strategy despite the Fukushima disaster. There are, however, a couple of changes in the post-Fukushima discourse. As expected, the Fukushima disaster and nuclear safety became the focal point in the discourse related to nuclear energy. Coverage of plant construction is no longer a major theme, which might reflect China's temporary freezing of plant construction shortly after the disaster. Interestingly, the discourse of nuclear energy has increasingly been coupled with climate change and carbon emission reduction.

D. Word Association

The difference between the sub-corpora can be revealed by the word association of "nuclear power". In the pre-Fukushima sub-corpus, "nuclear power" most often co-occurs with construction-related tokens. After the disaster, the phrase is associated not only with construction but also with accidents and safety (Table 9).

To summarize, the statistical discourse analysis shows that the government's concern over nuclear accidents and safety surged in light of the Fukushima disaster. Despite these safety concerns, the development of and investment in nuclear energy has not receded and remains prominent. A new development is that the newspaper discourse in China has connected nuclear energy more strongly with climate change. Nuclear energy is framed as a clean strategy to combat climate change. This can be considered as a way of justifying the continual development of nuclear projects.

4. Nuclear Safety Performance and Governance 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. Safety is a key consideration in nuclear model classification system, apart from nuclear reactors' cost-effectiveness, security and nonproliferation, grid appropriateness, commercialization roadmap and the fuel cycle. Building passive safety features is particularly important because they serve the safety net in case human errors have occurred, or auxiliary power is lost [33].

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 during the period 1970 to 1996. The majority of the more than 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 for 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 mostly traditional active safety features involving electrical or mechanical operations. While these traditional active safety features could be initiated automatically, they may also be initiated by the operators [14].

Gen II+ is a category specific to China. It updates the M3 design (a Gen II design) built at Daya Bay in the 1990s [34]. The addition of safety features raises its safety level to that of at least Gen III. 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 have been enhanced in upgrades of CPR-1000 [35]. The more recent APR-1000, ACP-1000 and ACC-1000 aimed at being a wholly Chinese design with safety characteristics equivalent to the best in the world [16]. Based on the latest safety regulatory standards, the safety design of existing CPR-1000 and ACP-1000 models has been improved substantially, adopting the defense-in-death safety principle, including: defense against extreme external events (earthquake and floods), improvement in safety functions (cooling and power supply), prevention and mitigation of severe accidents, environment monitoring and emergency response, and emergency cooling of spent fuel pool [36, 37].

Gen III reactors were designed in the 1980s and offered evolutionary improvements over earlier reactors. Generally, they have extensive engineered safety systems against loss of coolant accidents, improved digital control systems and ergonomically designed control rooms. These types of reactors have been operating from 1995 to date [33].

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. EPR (European Pressurized Reactor) and AP1000 belong to this category and are considered to be the state of the art in terms of safety. They have been purchased by China and are being built at Taishan (EPR) and Sanmen (AP1000) [16]. Recently constructed Gen III+ reactors in the West are generally considered to be safer than Gen II reactors due to their defense-in-depth safety design [38-40].

Chinese reactors are arguably up to date technologically because they were built mostly after 1990 (with current design technology) whereas reactors in the rest of the world were almost all built prior to 1990, utilizing Gen II technology [33, 41, 42]. Currently, nine Gen II+ and two Gen III reactors are in operation in China, and nine Gen II+ and seven Gen III (five Gen III, two Gen III+) reactors are under construction (Table 1, Table 2).

China's commercial NPPs are subject to inspections by the World Association of Nuclear Operators (WANO) and are also under the IAEA's inspections. Adopting international safety performance indicators, WANO inspections benchmark the safety performance of Chinese operators with international NPP operators [43, 44].

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 with their Gen II counterparts [40]. However, even the latest Gen III+ designs are not without their problems. The design of the digital control system of the EPR was criticized first by the UK safety regulator and was subsequently modified both in France and Finland. The Taishan NPP, which is currently under construction, is of an EPR design. This reactor has also been considered to fall short of international safety standards, requiring further modification [45].

4.1.2 Compliance with IAEA Standards

The IAEA is a collaborative organization and has set up a series of nuclear safety standards, including general and specific safety requirements [46] 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” [46], seven features have been assessed, namely, site characteristics, safety functions, possible radiation risks, radiation protection, engineering aspects, human factors, and long term safety [47]. The IAEA safety assessment helps identify areas for improvement for management systems and emergency response. Table 10 summarizes the areas for improvement of the operating NPPs in China, based on 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 the operating NPPs should be improved [47].

First, the site characteristics of the NPPs require improvement. The Ningde and Hongyanhe sites have a higher probability of earthquake as they are closer to the Circum-Pacific seismic belt, and so their anti-seismic capacity must be improved. Located in the coastal area of Guangdong, Daya Bay and Ling Ao are currently under in-depth assessment on the earthquake risk. Also, evaluations of the impact of secondary incidents such as tsunami resulting from an earthquake are being conducted on other sites. The anti-flood design of Qinshan might not be able to overcome extreme storm surge superimposed with the largest astronomical tide [47] (App II, p. 6).

Second, nuclear safety is highly dependent on safety management, especially emergency response planning. Most NPPs in operation have some limitations in emergency response. 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 for people, property and the environment in any nuclear or radiological emergency [46]. Daya Bay and Tianwan has no sound response plan in place for a situation where multiple reactors enter a state of emergency simultaneously. The current response plan of Tianwan and Ling Ao is not complete and covers only some of all the potential severe accidents. The emergency response control centers of Qinshan phase II, Ningde and Hongyanhe are not completed yet. There are no severe accident management guidelines for Qinshan phase I, and optimization of resource allocation is needed to better meet the requirements of an emergency response [47].

Apart from the above, it has been reported that some common specific engineering and management issues require attention and improvement [48, 49]. These include: insufficient 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, tackling survivability and availability; inadequate preparation for integrated, coordinated, emergency response at multi-unit sites; weak monitoring and control of hydrogen explosion; 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.

4.1.3 Safety Performance

Statistics shows that China has a strong track record in nuclear safety in terms of both incidents [50] (Table 11) and the predicted core damage and release of its self-constructed nuclear reactors [51-62] (Table 12). All nuclear events that have occurred in China have been either Level 0 or 1 (low-level) incidents. Table 11 highlights the level of each nuclear incident that has occurred in China based on the INES, defined by the IAEA [63]. 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" [64]. 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 [52].

Two key indicators have been developed as part of the safety clearance of reactor design, namely, Frequency of Core Damage (CDF) and Frequency of Large Release (LRF). These estimates of nuclear risk are used to benchmark the safety performance of NPPs [56]. The strictest safety levels set by NNSA (2006) are less than 1×10^{-4} per reactor year for CDF and less than 1×10^{-5} per reactor year for LRF regarding existing reactors, and are less than 1×10^{-5} per reactor year for CDF and less than 1×10^{-6} per reactor year for LRF regarding new reactors [51]. The frequency table (Table 12) shows that all operating reactors in China have attained LRF and CDF values well below the strictest limits set by NNSA.

4.1.4 Speed and Scale of Nuclear Project Development

China reveals its 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 [16]. 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 introduced in the 1980s [65]. China has been developing its own designs and importing designs from overseas: M310 and EPR from France, VVER-1000 from Russia, CANDU-6 from Canada and AP1000 from the US. Although China has chosen the best designs in the world, each requires specialist knowledge and facilities to maintain. The cost of investment and the scale of manpower required for both locally and overseas-designed models is onerous and high [16]. China has been working on a broad range of nuclear technologies to make herself independent of external supply and to become a leader in nuclear technology. New technologies are being explored in areas such as reprocessing and nuclear waste disposal, high temperature gas reactors and molten salt reactors using thorium [16].

4.2 Nuclear Safety Governance

4.2.1 Governance Structure

The decision-making process for nuclear development and safety regulation 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, authority over the energy sector in China was distributed between more than ten government bodies [66]. 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 [67-69]. The State Council approved the restructuring plan of the NEA in June, 2013 (the current structure of energy bureaucracy is illustrated in Figure 5 [68-72]). 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 [69, 72]. Following the Fukushima crisis, the NNSA is now authorized to develop regulations and guidelines for nuclear safety, and the licensing and regulating of nuclear facilities and materials, and to draft emergency response plans. It is administered under the Ministry of Environment Protection (MEP) but reports to the State Council directly [73] (Figure 5).

Although the NNSA reports to the State Council directly, in practice such a hierarchical system leaves implementation of the nuclear safety agenda ambiguous. An issue identified by the Integrated Regulatory Review Service (IRRS) team is the implementation of legal responsibility for radiation protection regarding occupational radiation workers [74]. 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 governmental agencies and industries. No authority has been delegated the administrative/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 that the regulatory system should be consolidated and NNSA should 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 have laid down the key principles that nuclear power is a strategic energy source and should be actively pursued to meet the country's growing demand for energy sources [32, 75]. Shortly after the Fukushima crisis, 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 in March 2011 [76]. Following this, a nine-month comprehensive safety review on nuclear power was undertaken by the Chinese government [77]. Safety inspections were conducted regularly on all nuclear projects. To ensure nuclear safety, the Chinese government has invited the Operational Safety Review Team (OSART) under IAEA, the WANO and the China Nuclear Energy Association (CNEA) (with the Research Institute for Nuclear Power Operations, RINPO) to conduct regular external safety reviews for NPPs, typically on a yearly basis. China requested and hosted 12 OSART missions in October 2011 [16]. In May 2012, a new safety plan for nuclear power, the 12th Five-Year Nuclear Safety Plan and the 2020 Vision, was approved in principle [30]. The State Council reiterated that the country would put safety and quality first in nuclear power development [31]. In parallel, in an unprecedented move to improve the transparency of nuclear regulation, the government published the Comprehensive Safety Inspection Report about National Civilian Nuclear Facilities, and called for public opinion on the new nuclear safety plan [47]. The State Council also 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) [78]. China would commit RMB 80 billion (USD 13 billion) in three years' time to improve nuclear safety at 41 reactors (both in operation and under construction). However, the new nuclear safety plans, which are the key official documents that provide the blueprint for China's future nuclear safety development, are not available to the public, calling into question the government's commitment to improve information transparency and public participation. List of plans and regulations on nuclear safety in China are highlighted with its main contents listed in Table 13.

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 [9]. 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 [79]:

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 nuclear power plants [69]. MEP (NNSA) has also recognized "the competency gaps in performing independent audit calculations as a part of safety assessment".

The lack of skilled nuclear engineers is presenting a challenge to the safety culture in NPPs. Although a number of employees in the nuclear corporations is sent to other countries for training or is trained in China by international experts, for example, some have received trainings offered by the Daya Bay [28], this can hardly compensate the lack of skilled engineers properly trained through tertiary education. By 2020, China would require more than 10,000 graduates majored in nuclear engineering and science degrees, but enrolments in nuclear or related disciplines in universities has declined since the 1990s [80]. Increasing investments and collaborations in joint training programs with universities have been made by the major nuclear corporations in China in response to the need for specialized workforce in future [69, 80]. The manpower shortages have not only affected the inspections of plant constructions and daily operations, but also nuclear safety regulation [74]. The IRRS [74] has suggested that sufficient financial and human resources are to be channeled to the NPPs to maintain the regulatory infrastructure, and recommended that specialized management programmes be set up to train the management experts with technical competence. The NNSA of China plans to expand its workforce from 300 to 1,200, according to the government documents [81]. In the UK, professionals working in regulatory agencies have to possess relevant qualification plus ten years' experience of nuclear safety in the industry. The US Nuclear Regulatory Commission (USNRC), NNSA's US counterpart, had around 4,000 permanent staff in 2012 [82]. With a net installed capacity of nuclear energy of 100 GW [83], the ratio of regulatory staff to installed capacity was approximately 40 staff/GWe in the US. If China reaches 58 GWe installed capacity by 2020, the number of regulatory staff/GWe will be 21, approximately half of the US level. To meet the increasing nuclear capacity, NNSA would have to almost double its workforce to meet the US staffing level. The regulator's hiring of safety inspectors in China is difficult because of the requirement for many years of nuclear experience to be 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 post graduating from a master program. Further, it takes time for the workforce to acquire the technical safety expertise.

4.2.4 Postponement of New Nuclear Projects Approval

After a temporarily suspended construction of new NPPs aftermath the Fukushima crisis, plans to build reactors continue without any signs of decrease. For nuclear new builds in China, though GIIIs will be 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 the major share of the nuclear market in China in the near future. 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); and, third, GII projects carry a much better track record than their GIII counterparts in terms of equipment supply and site construction [84]. Thus, future nuclear projects are unlikely to abruptly shift to GIII from GII. 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 [16]. 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 in the near future.

5. Discussion

This study analyses the government's concern over nuclear safety after Fukushima, based on an interdisciplinary approach. This paper dissects the issue from both social science and engineering perspectives, by deciphering attitudes towards nuclear safety via the state-run Chinese newspapers, and by researching both technical and policy documents on nuclear safety performance and governance in China. Our analysis ultimately answers the single most 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 accidents and safety surged dramatically after the Fukushima disaster. Apart from safety concerns, the development of and investment in nuclear energy remains prominent. China on the whole has been making good efforts to improve nuclear safety performance and has maintained a reasonably 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. 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 NNSA to improve their site characteristics, safety management and emergency planning in some ways.

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 still appears to exhibit the following deficiencies:

1. Institutional fragmentation and overlap
2. Eagerness to present a comprehensive and internationally recognized safety plan, but with inadequate transparency for public scrutiny
3. 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
4. Delay in approval of new nuclear projects in the short term, but with increasing number of new nuclear plans in the near future

Nuclear power is an unforgiving technology. It requires the application of high standards across the sectors of design, construction and operation. People and skills are crucial. How these people are trained, deployed and organized are 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. It has yet to be determined 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 Nuclear Energy and Climate Change

The newspaper discourse in China has now more strongly connected nuclear energy development with climate change. The reframing of new NPP as a means of climate change mitigation in the news media was reported in other countries such as the UK before the Fukushima accident [85]. In China, nuclear energy is framed as a clean option to combat climate change. Such linkage reflects the Chinese government's intention to tackle climate change via clean energy technology, especially nuclear power, and could serve as a means to justify the continual development of nuclear projects to meet the energy demand post-Fukushima. Coal is the primary energy source, accounting for about 66% in China's total energy consumption in 2012 [86]. Compared with other energy sources, coal is a relatively low-cost option to address the growing energy demand due to fast socio-economic development in China. However, heavy reliance on coal has resulted in a number of environmental problems, such as greenhouse gas emissions, air pollution and acid rain. As China aims to cut CO_2 emissions intensity by at least 40% below 2005 level by 2020, clean energy alternatives, including renewable energy and nuclear energy, becomes the popular options [87]. According to the 12th Five-Year Energy Development Plan [88] and the Policies and Actions for Addressing Climate Change (2012) [89], the Chinese government emphasizes on the diverse development of energy and the increasing share of clean energy in the energy mix. As reported by IAEA, nuclear power is one of the lowest CO_2 emitters among existing energy technologies and can improve energy security at competitive economic costs [90]. At the moment, renewable energy only accounts for a small portion of energy supply and presents challenges on grid integration and transmission over a long distance in China. As such, nuclear energy offers a more promising and practical solution to tackle both climate change and fast growing energy demand [9].

5.3 Areas for Improvement in China

IAEA is the main organization among the international communities that have established an elaborate system to ensure nuclear safety around the world [80]. After the Fukushima accident, IAEA published an action plan to strength the global nuclear safety framework [91], 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.

5.3.1 Nuclear Safety Standards and Nuclear Reactor Technologies

In China, the current Gen II+ and future nuclear reactors are mostly designed and developed at home [51]. Whilst it is important to encourage China to transit to Gen III technologies, it is also crucial for China to ensure that its own Gen II+ designs, such as CPR1000+ and Gen III+ CAP1000, fully comply with international safety standards. This will not only strengthen confidence in China's nuclear capability but will also greatly facilitate the commercialization of China's nuclear technologies [38-40]. China may also want to standardize the nuclear reactor technologies among different nuclear utilities. Adopting an identical design would allow an easier comparison of operations, identification of problems and solutions, development of common training programs, and establishment of industry-wide best practices.

5.3.2 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 proper attentions. Some major nuclear facilities along the coastline appear not to have adequately taken into account the probability of earthquakes or flooding. Emergency response planning undertaken by NPPs such as Daya Bay is yet to address multiple nuclear accidents (Table 10, 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 the independent third-party inspection and monitoring of nuclear safety plans and facilities on-site and off-site.

5.3.3 Regulatory System for Nuclear Safety Management

The institutional structure of nuclear safety management in China needs to be reviewed. In line with the suggestion of NNSA [73], China should set up an independent regulatory unit delegated with significant authority to manage nuclear safety. The IRRS [74] 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 in terms of nuclear safety management would best be differentiated. The communication of emergency response between nuclear safety authorities and different NPPs would be best laid out clearly. Whilst the national government is in charge of overall emergency planning, local governments 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 but effective institutional structure for nuclear safety management at various levels of governance. Clear roles and responsibilities would be best assigned to individual units involved in nuclear safety management.

As the nuclear safety culture and capacity cannot be developed overnight, a process-based risk-informed regulatory approach could provide the flexibility needed for China's safety regulation. The Fukushima disaster has demonstrated that accidents or extreme events may still occur. In this case, 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 wants 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 [92]. 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 [59] 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.

5.3.4 Information Transparency and Public Participation

Transparency and public participation have been considered an absolute condition 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 [93]. Immediately following the Fukushima crisis, several regulations on nuclear communication were enacted, including the Program and Notice on Nuclear Safety Information Disclosure enacted by MEP and NNSA. Furthermore, nuclear safety information was disseminated throughout China by 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]. Regrettably, the disclosure of information by the government does not seem to reduce public fear, although the government remains the most trusted information provider [94]. Public participation in and access to information on nuclear constructions and assessments remain marginal in China [94]. 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 government should continue building trust in its nuclear safety governance. Whilst the Chinese government's ongoing attempts to disclose the technical details of the safety report and radioactivity to the public could boost public trust, such trust would be better developed if the government would also carefully reconsider its manner of communicating nuclear safety information to the public. For instance, presenting safety information in layman's terms so as to be understandable by the public could positively contribute to effective nuclear safety governance in the long run.

5.3.5 Capacity Building on Safety Personnel and Safety Culture

China has been making efforts to boost the workforce in nuclear industry to meet the 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. Regular rotation of resident inspectors is recommended to avoid regulatory capture. Also, in the absence of a well-developed safety culture, it is doubtful whether China would be able to introduce sweeping reform in nuclear safety management and ensure that the large number of new nuclear plants is safe. 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 run. 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.

5.3.6 International Collaboration

The nuclear reactors designed by China have incorporated overseas nuclear technology design. China's Gen II+ technologies are based upon French M3 technologies, and China's Gen III+ utilizes AP1000, 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 difference between the Chinese and the Western world may shape the safety culture of individual civilizations. There is a huge difference in staff-supervisor interaction between the East and the West. Chinese staff tends to use indirect methods to express their views in face of adverse events [95]. Such cultural difference 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 [96]. However, in China, it is possible that such indirect culture of reporting by Chinese staff and concerns about how whether one would get blamed if one reports an adverse event directly to his/her supervisor, would impact the nuclear safety culture in China. 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, in an effort to strengthen its internal nuclear safety management capacity over the long-run.

6. Conclusion

Our research raises the important question of whether China's response to nuclear safety following the Fukushima crisis is genuine or rhetoric. Our statistical discourse analysis demonstrates that nuclear accidents and safety have become the two high frequency words dominating the news corpora of nuclear power in China post-Fukushima. As the news media in China is a crucial channel for policy direction and promotion, our findings reflect the Chinese government's significant concern over nuclear safety. These concerns have also been translated into policy measures, e.g. 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 introduced and developed in China.

Undeniably, China's priority on nuclear safety is beyond rhetoric and has been moving progressively towards genuine. However, various concerns remain. China's safety policy and governance is continuously impeded by its institutional fragmentation and overlap, unclear roles and responsibilities for individual departments, inadequate public transparency, lack of sufficient experienced safety professionals, weak safety culture, and an ambitious plan for a three-fold increase in nuclear capacity by 2020, and more beyond. To ensure that nuclear safety continues to be a key priority in the long term, nuclear safety performance in China may require specific institutional reform, cultural and policy change. We suggest that China should standardize design and safety standards, strengthen nuclear safety management and emergency response by means of independent third-party inspection, reform regulatory structure to reduce institutional fragmentation, adopt a preventative approach towards nuclear safety regulation, improve information transparency and public participation, and strengthen the safety culture and international collaboration for capacity-building.

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Figure 1. Number of nuclear reactors in operation and under construction by country (as of 2014)

Source: [10-12]

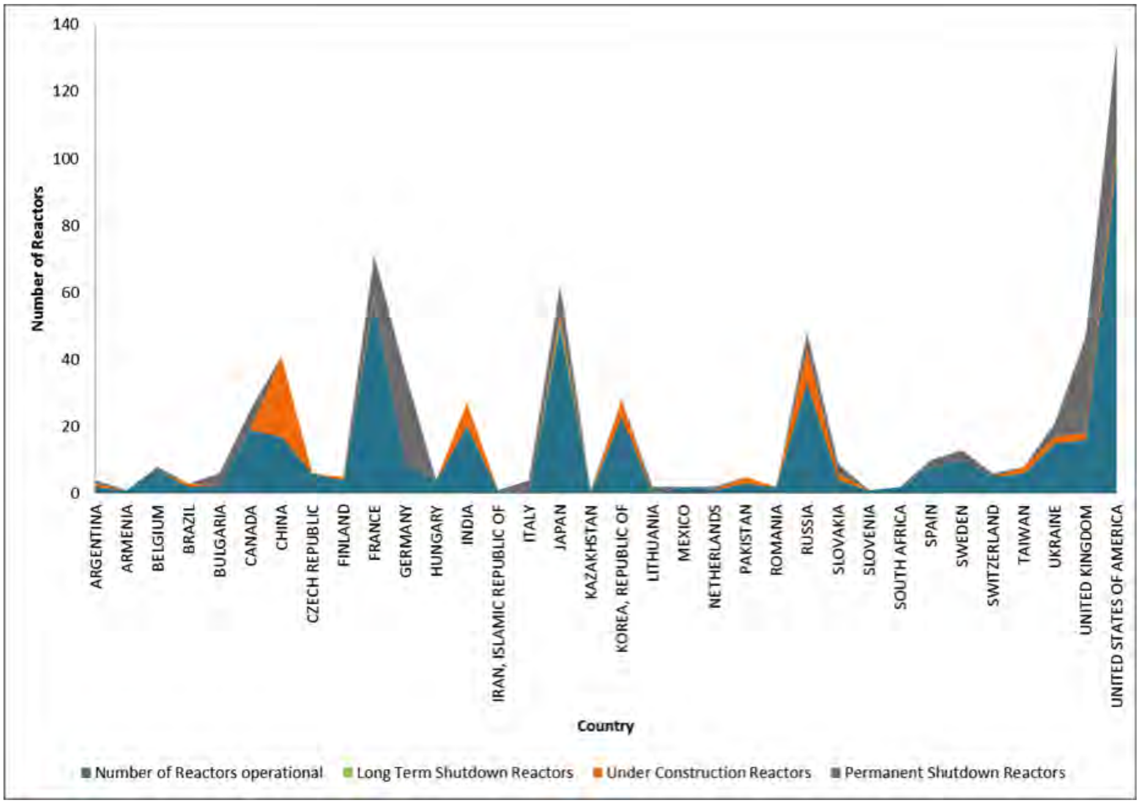

Figure 2. Nuclear power stations and generation type in China (as of 2014)
Source: [15, 16]

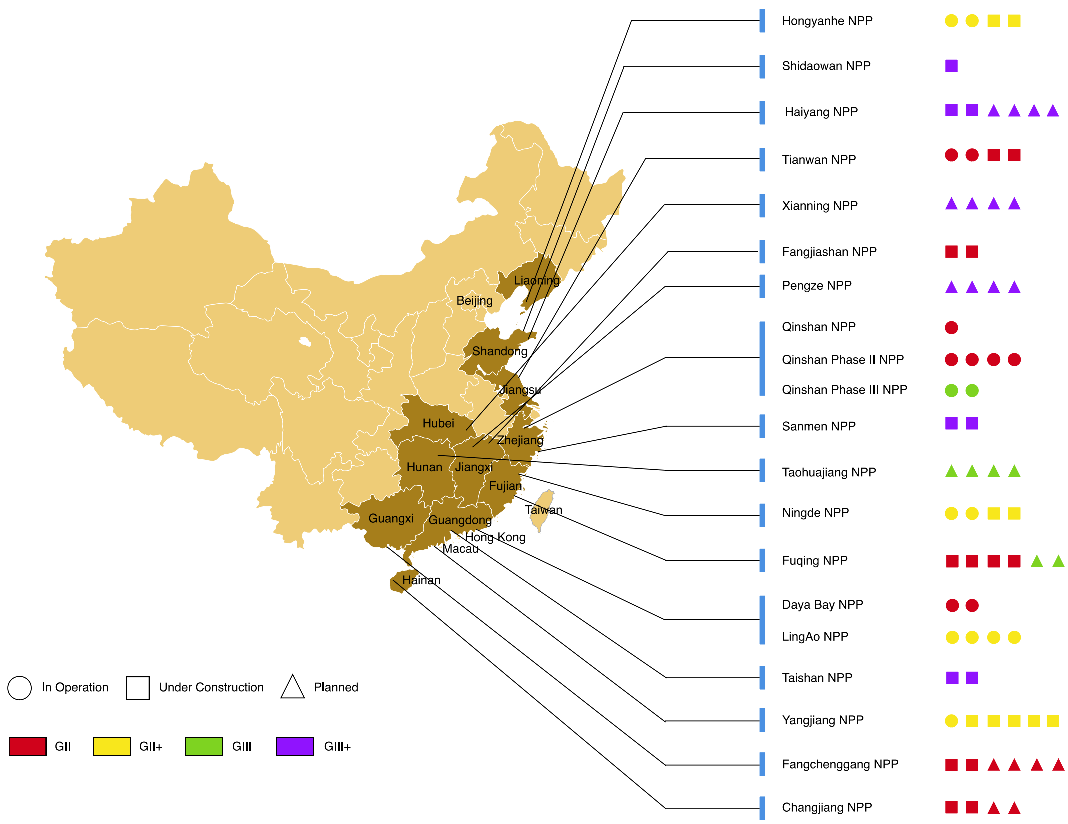

Figure 3. Themes generated for the pre-Fukushima sub-corpus
Source: Statistics generated by T-Lab, a computational tool

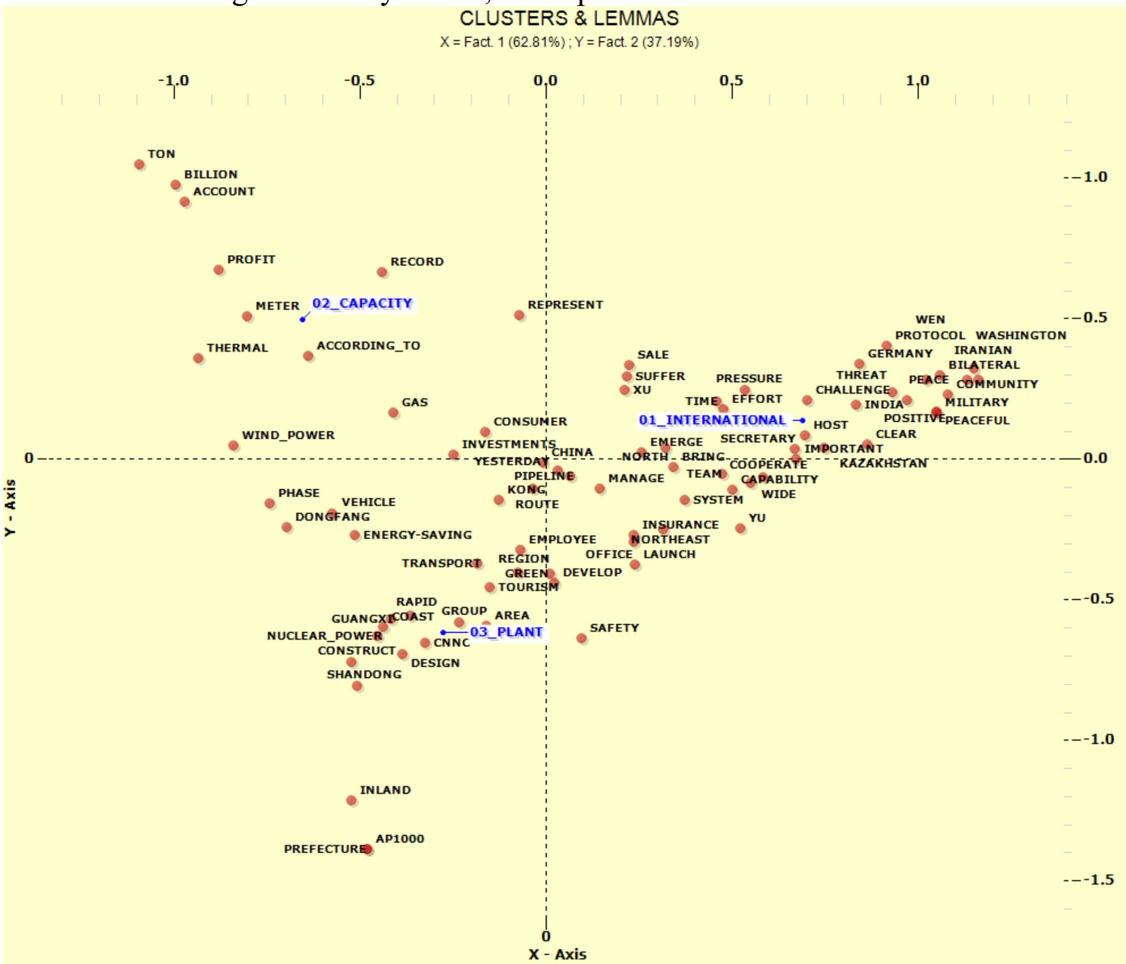

Figure 4. Themes generated for the post-Fukushima sub-corpus
Source: Statistics generated by T-Lab, a computational tool

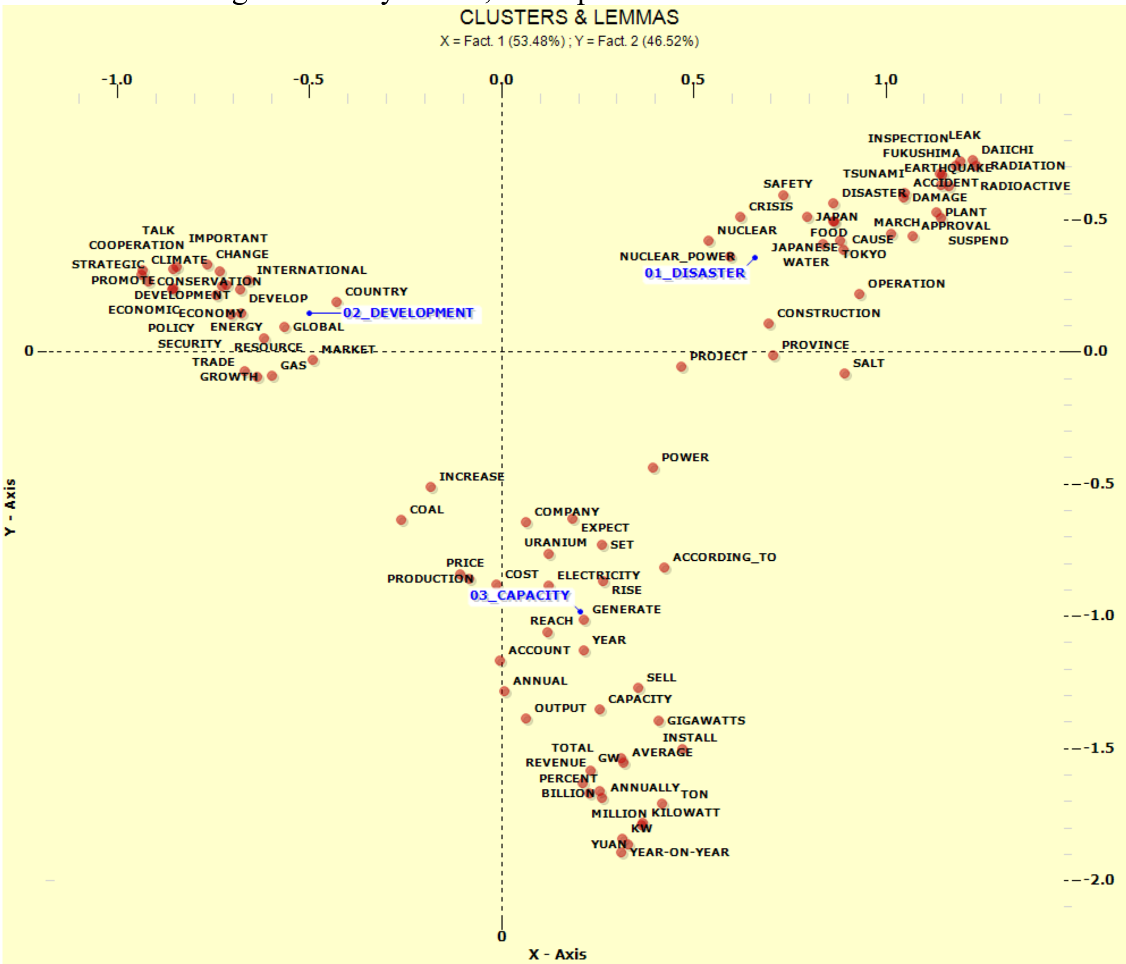

Figure 5. Key bodies involved in nuclear safety regulation in China

Source: [68-72]

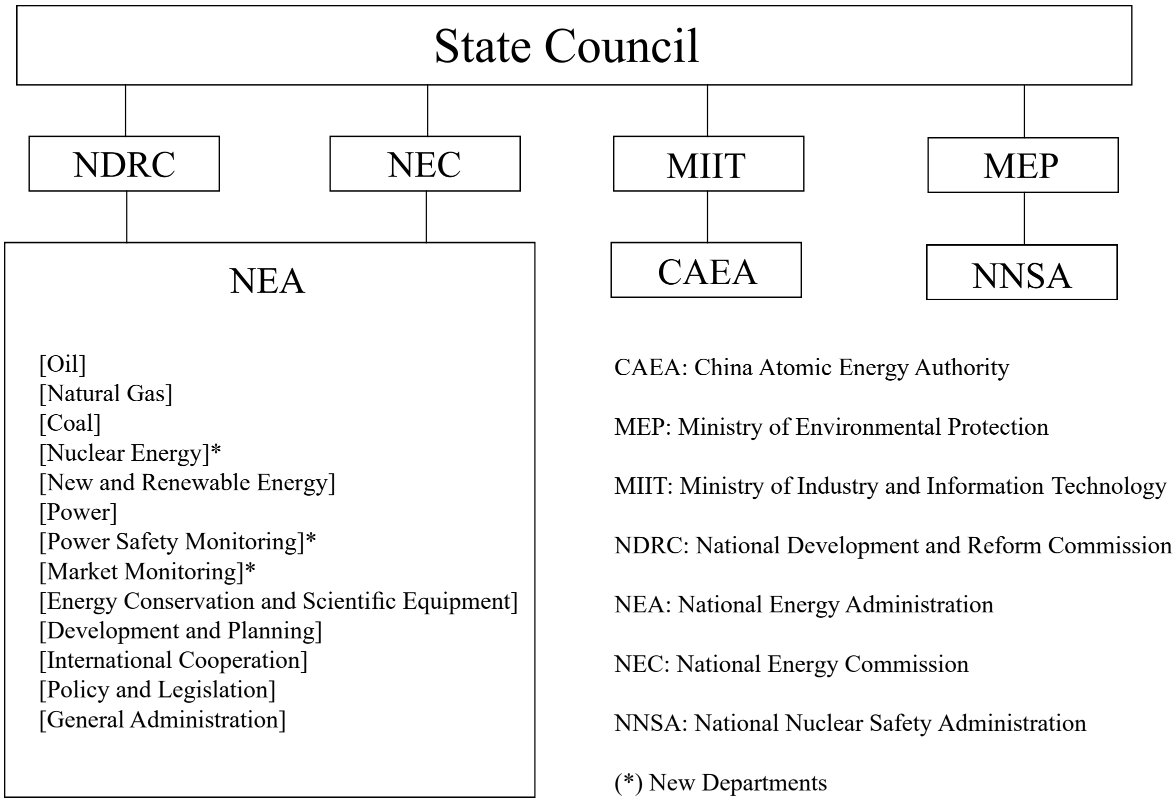

Table 1. Status of nuclear reactors in China (as of 2014)
Source: [15, 16]

Location	Plant	Status	Generation Type	Reactor Type	Units
Fujian	Fu Qing	Under Construction	II	CNP-1000	4
	Fu Qing	Planned	III	ACP-1000	2
	Ning De	In Operation	II+	CPR-1000	2
	Ning De	Under Construction	II+	CPR-1000	2
Guangdong	Daya Bay	In Operation	II	M310	2
	Lingao	In Operation	II+	CPR-1000	4
	Tai Shan	Under Construction	III+	EPR	2
	Yang Jiang	In Operation	II+	CPR-1000	1
	Yang Jiang	Under Construction	II+	CPR-1000	5
Guangxi	Fang Cheng Gang	Under Construction	II	CPR-1000	2
	Fang Cheng Gang	Planned	II	CPR-1000	4
Hainan	Chang Jiang	Under Construction	II	CNP-600	2
	Chang Jiang	Planned	II	CNP-600	2
Hu Bei	Xian Ning	Planned	III+	AP1000	4
Hu Nan	Tao Hua Jiang	Planned	III	M310	4
Jiang Su	Tian Wan	In Operation	II	AES-91	2
	Tian Wan	Under Construction	II	AES-91	2
Jiang Xi	Fang Jia Shan	Under Construction	II	CPR-1000	2
	Peng Ze	Planned	III+	AP1000	4
Liaoning	Hong Yan He	In Operation	II+	CPR-1000	2
	Hong Yan He	Under Construction	II+	CPR-1000	2
Shandong	Hai Yang	Under Construction	III+	AP1000	2
	Hai Yang	Planned	III+	EPR	4
	Shi Dao Wan	Under Construction	III+	AP1000	1
Zhejiang	Qin Shan	In Operation	II	CNP-300	1
	Qin Shan Phase II	In Operation	II	CNP-600/650	4
	Qin Shan Phase III	In Operation	III	CANDU-6	2
	San Men	Under Construction	III+	AP1000	2

Table 2. Status of nuclear reactors by generation type in China (as of 2014)
Source: [15, 16]

Generation Type	In Operation	Under Construction	Planned	***Total***
II	18 (9)	21 (9)	6	**45 (18)**
III	2	7 [2]	18 [4]	**27 [6]**

Total	20	28	24	**72**

Note: The number in () represents the number of reactors adopting GII+ technologies and the number in [] represents the number of reactors adopting GIII+ technologies.

Table 3. Period covered and size

Sub-corpus	Period	No. of Files	No. of Words
Pre-Fukushima	Year 1 (Mar 12, 2008-Mar 11, 2009)	155	175,368
	Year 2 (Mar 12, 2009-Mar 11, 2010)	225	
	Year 3 (Mar 12, 2010-Mar 11, 2011)	226	
Post-Fukushima	Year 4 (Mar 12, 2011-Mar 11, 2012)	331	153,776
	Year 5 (Mar 12, 2012-Mar 11, 2013)	145	
	Total =	1,082	329,144

Table 4. High frequency content words

Sub-corpora	High frequency content words (in descending order of frequency)
Pre-Fukushima	China, power, nuclear, country, world, nuclear_power, energy, percent, development, year, billion, Chinese, market, #capacity, building, countries, #technology, #national, #yuan, #state
Post-Fukushima	China, nuclear, energy, #Japan, country, power, world, nuclear_power, development, percent, chinese, countries, year, market, building, #coal, billion, plant, #cooperation

Note: # indicates that the word is particularly high in the associated sub-corpus.

Table 5. Rank and frequency of "safety"-related words in the two sub-corpora

Terms	Pre-Fukushima		Post-Fukushima	
	Rank	Frequency	Rank	Frequency
"safety"	387	78	37	381
"nuclear safety"	853	37	118	161
"inspection"	1801	15	699	40
"inspections"	3952	5	931	29
"standard"	317	92	199	110
"standards"	409	73	188	114
"accident"	1579	17	155	129
"accidents"	3722	5	726	38

Table 6. Top 20 sub-corpus specific words/phrases (i.e. words/phrases whose frequency is much higher in the specified sub-corpus than the other sub-corpus (in descending order))

Sub-corpus	Words / phrases that are more specific in the sub-corpus
Pre-Fukushima sub-corpus	Shenzhen, wind_power, Iran, sign, new_energy, sanction, Hu, weapon, company, capacity, mW, deal, disarmament, Obama, Green, President, mainland, India, yesterday, carbon

Post-Fukushima sub-corpus	Japan, safety, Japanese, radiation, tsunami, earthquake, disaster, salt, radioactive, March, accident, Tokyo, emergency, leak, inspection, food, vegetable, crisis, suspend, Xinjiang

Table 7. Three-theme model generated for the Pre-Fukushima sub-corpora

Theme #A1: PLANT CONSTRUCTION (19.7% of the Pre-Fukushima corpus)
Ten characteristic words: nuclear_power, power, energy, capacity, plant, wind, reactor, technology, percent, construction
Characteristic text samples for the theme: *1.* To realize the goal, the government will invest billions of yuan in the construction of nuclear power stations, wind farms, solar power plants and research of renewable energy technologies, Zhang said. Official figures show that renewable energy accounted for 9.9 percent of total energy consumption last year, compared to 8.5 percent in 2008. *2.* According to the National Energy Administration, China has approved nuclear power plants with total capacity of 25.4 gW this year, with further capacity of 13.35 gW under construction. China now has 11 nuclear power units under operation, with a total capacity of around 10 gW. The government plans to increase nuclear capacity to around 70 gW by 2020.
Theme #A2: INTERNATIONAL COOPERATION (19.0% of the Pre-Fukushima corpus)
Ten characteristic keywords: Iran, nuclear, change, international, cooperation, climate, weapon, Hu, security, issue
Characteristic text samples for the theme: *1.* President Hu Jintao attaches importance to nuclear security and closer cooperation among developing nations. President Hu Jintao is attending a high-profile global safety summit in Washington DC on April 12, when 47 leaders of countries with nuclear capability will gather to discuss nuclear safety, a crucial issue for international security. *2.* To achieve the target, Obama mapped out three specific and interlinked goals for the world: Nuclear disarmament, nuclear nonproliferation and the pursuit of nuclear security. That showed the US has changed its unevenly balanced nuclear policy. In the past, Washington has attached more importance to non-proliferation and nuclear security efforts while ignoring nuclear disarmament.
Theme #A3: CAPACITY AND INVESTMENT (11.7% of the Pre-Fukushima corpus)
Ten keywords: yuan, million, city, Shenzhen, company, mainland, investment, market, bank, service
Characteristic text samples for the theme: *1.* Hong Kong and Shanghai-listed Shanghai Electric said it planned to invest 2 billion yuan over the next three to five years to expand into wind and nuclear_power equipment manufacturing. It expects wind power equipment orders to total 10 billion yuan annually over the next three to five years and expects nuclear_power equipment orders to total 5 billion yuan to 6 billion yuan annually … *2.* The total annual turnover of China's environmental industry reached 700 billion yuan, among which, 62.5 billion yuan came from environmental protection related products, 50 billion yuan from environmental services, 420 billion yuan from recycling of resources, and 170 billion yuan from clean production equipment.

Table 8. Three-theme model generated for the Post-Fukushima sub-corpora

Theme #B1: JAPANESE DISASTER (20.8% of the Post-Fukushima corpus)
Ten characteristic words: nuclear, Japan, plant, safety, nuclear_power, reactor, Fukushima, radiation, earthquake, tsunami
Characteristic text samples for the theme: *1.* Making nuclear plants safe and secure (By Yin Xiaoliang). 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. *2.* Nuclear experts: No need to worry Daya Bay plant. Shenzhen's two power plants have not been affected by the Japan earthquake and would not explode if faced with the same situation as the plants of

Fukushima, nuclear experts said in an interview Monday, responding to the public concern over nuclear safety.
Theme #B2: COOPERATION AND CLIMATE CHANGE (11.4% of the Post-Fukushima corpus)
Ten characteristic keywords: cooperation, development, climate, economic, change, military, promote, defense, strategic, security
<u>Characteristic text samples for the theme:</u> *1.* … and make greater contributions to the cause of addressing global climate change. China will continue to promote international negotiations on climate change, take an active part in UN climate change conferences, and support the coming Durban climate change conference to achieve comprehensive and balanced results in implementing the Bali Road Map, and make reasonable, … *2.* Adapting to Climate Change. During the 11th Five-Year Plan period, China strengthened scientific research in and impact evaluation of climate change, improved relevant laws and policies, and enhanced the capability of key sectors to adapt to climate change, so as_to reduce the negative impact of climate change on economic and social development and people's lives.
Theme #B3: CAPACITY AND INVESTMENT (12.7% of the Post-Fukushima corpus)
Ten keywords: percent, billion, yuan, million, year, coal, price, company, market, increase
<u>Characteristic text samples for the theme:</u> *1.* China's coal-fired power producers complain that surging coal costs and artificially low electricity prices have hurt their profits. Investment in the coal-fired power sector stood at 105.4 billion yuan in 2011, compared with 94 billion yuan in hydropower, 74 billion yuan in nuclear_power and 82.9 billion yuan in wind power. *2.* By 2015, carbon dioxide emission per-unit GDP would_be reduced by 17 percent and energy consumption per-unit GDP by 16 percent as compared with that in 2010; the proportion of consumption of non-fossil energy to the consumption of primary energy would_be increased to 11.4 percent; and the acreage of new forests would increase by 12.

Table 9. 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	plant, China, Guangdong, capacity, nuclear, technology, country, power, energy, Daya_Bay, build, construction, plan, province, development, national, project, total, Qinshan, industry
Post-Fukushima sub-corpus	plant, Fukushima, China, safety, nuclear, japan, Daiichi, energy, country, Guangdong, project, development, crisis, plan, leak, earthquake, approval, construction, accident, tsunami

Table 10. Areas where operating nuclear power plants need to improve with specific notes, by IAEA standards
Source: [47]

Nuclear Power Plants in China (with Reactor Generation and Type) / **IAEA Standards Criteria**		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	1							2	3
	Tsunami	3					4	4		
	Flood		5	5	5					
	Other External Events	6	6	6	6	6				
Engineering Aspects	Facilities								7	7
Human Factors	Emergency Response & Management	8	11	9		8, 9	9	9	10	10

Notes:

1. Need to conduct in-depth evaluation on the earthquake risk of Daya Bay Nuclear Power Plant, and complete necessary improvements.
2. For uncompleted emergency response control center, need to make appropriate planning to improve the anti-seismic capacity.
3. Need to conduct more in-depth analysis and tsunami drills.
4. Need to enhance the capability of anti-tsunami for each NPP in the coastal areas of Guangdong.
5. Problem with the design basis of flood; need for flood protection enhancement.
6. Need to conduct probability risk assessment of external event.

7. For hydrogen removal facilities, program design and instrument selection has completed; need to conduct equipment qualification test.
8. Need to study response plan when multiple reactors simultaneously enter a state of emergency.
9. Need for emergency planning for non-specific non-severe accidents.
10. Need to install emergency response control center.
11. Need for more detailed safety management guidelines, emergency response planning and resource optimization.
12. Need for progressive design.

Table 11. No. of incidents of major operating nuclear reactors in China from 2009 to 2014
Source: [50]

<table>
<tr><th rowspan="2"></th><th rowspan="2">Operation Starting Date</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></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></tr>
<tr><td>Daya Bay unit 1</td><td>Feb. 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></tr>
<tr><td>Daya Bay unit 2</td><td>May 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></tr>
<tr><td>Ling Ao unit 1</td><td>May 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="4">3</td><td rowspan="4">0</td></tr>
<tr><td>Ling Ao unit 2</td><td>Jan. 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>Sep. 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>
<tr><td>Ling Ao unit 4</td><td>Aug. 2011</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>7</td><td>0</td><td>2</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td>Ningde unit 1</td><td>Apr. 2013</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>10</td><td>0</td><td>9</td><td>0</td></tr>
<tr><td>Hongyanhe unit 1</td><td>Jun. 2013</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>12</td><td>0</td><td>5</td><td>0</td></tr>
<tr><td>Qinshan unit 1-5</td><td>Dec. 1991</td><td>2</td><td>0</td><td>5</td><td>1</td><td>10</td><td>0</td><td>5</td><td>0</td><td>5</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td>Tianwan unit 1-2</td><td>May 2007</td><td>3</td><td>1</td><td>2</td><td>0</td><td>1</td><td>0</td><td>2</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Table 12. Frequency of Large Release (LRF) and Frequency of Core Damage (CDF) for major operating nuclear reactors in China
Source: [51-62]

	Daya Bay	Qinshan phase I	Qinshan phase II	Qinshan phase III	Tianwan	Ling Ao phase I	LingAo phase II	Ningde	Hongyanhe	US NRC Standard (2001)	China NNSA Standard on old NPP (2006)	China NNSA Standard on new NPP (2006)
	II - French M310	II - CNP300	II - CNP600	II - Candu6	II - VVER1000	II - French M310	II+ - CPR1000	II+ - CPR1000	II+ - CPR1000			
CDF	2.13×10^{-5}	$< 1\times10^{-4}$	2.42×10^{-5}	$< 1\times10^{-5}$	3.3×10^{-6}	1.94×10^{-5}	1.53×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	$< 1.0\times10^{-4}$	$< 1.0\times10^{-4}$	$< 1.0\times10^{-5}$
LRF	2.45×10^{-6}	$< 1\times10^{-5}$	$< 1\times10^{-5}$	$< 1\times10^{-6}$	6.4×10^{-8}	2.45×10^{-6}	1.94×10^{-6}	$< 1\times10^{-6}$	$< 1\times10^{-6}$	$< 1.0\times10^{-5}$	$< 1.0\times10^{-5}$	$< 1.0\times10^{-6}$
Source	[51, 54]	[51]	[51, 58]	[52]	[71]	[51, 54]	[51, 54]	[51, 62]	[51, 62]	[53]	[51, 60]	[51, 60]

Table 13. 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 market-oriented mechanism, innovations in research and development, legalization and regulation, talent training, tax/investment incentives, and nuclear fuel security/post-processing funds; (2) By 2020, the goal of 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 research and development on nuclear technology and application; (3) Improve emergency system for nuclear accidents; (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 steadily; (2) Only arrange a few fully demonstrated coastal sites during the 12th Five-Year period and exclude inland sites; (3) Develop new NPPs based on the highest safety standards around the world. New NPPs must meet the safety requirements of Gen III technology. (4) By 2020, the goal of installed capacity for in-operation NPPs and under-construction NPPs is 58GWe and 30GWe, respectively.

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