A Book of Changes in Engineering

On Becoming a Good Engineer in China

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BY
XI JIN

DISSERTATION SUBMITTED 2016

AALBORG UNIVERSITY
DENMARK

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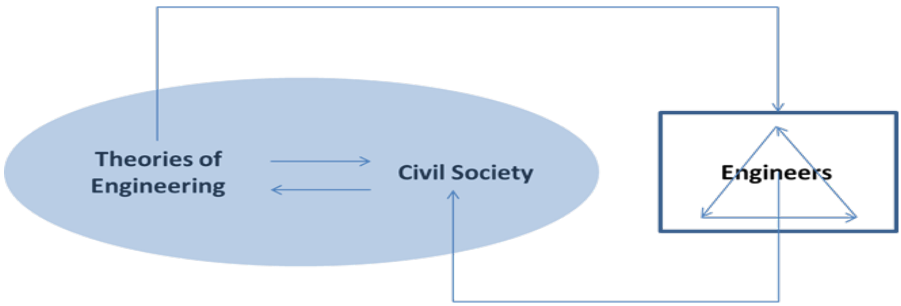
ENGLISH SUMMARY

The question "how to become a good engineer?" is complicated because being a good engineer has many meanings and there are thus different approaches as to how to bring about the necessary changes in practice. The "scientific" or academic approach emphasizes the importance of establishing a closer relationship between engineering and science. The "economic" or technical approach stresses the need to strengthen the economic efficiency of engineering activity. My approach to answering this question is inspired by the perception that engineering is a form of socially responsible practice. These three meanings of engineering can be expressed by a closed loop that indicates the interactions of the cultural elements.



In chapter 1 I discuss these three elements. Theories of engineering refer to the philosophical and methodological thinking that is reflected in engineering practices. The civil society refers both to the sources of theories and a space where engineers manifest the human meaning of engineering. Engineers are practitioners. Therefore, they are often positioned in an organization – the black-box in this diagram. It is indicated that the evolution of engineering for sustainability requires a circulation of this loop. This circulation can be manifested by different types of activities. In this thesis engineering design as an activity is focused on because it is regarded as the most important element of engineering. In order to study this activity some sociological and anthropological methods are used, specifically interviews supplemented with a participant observation in a nuclear power engineering company.

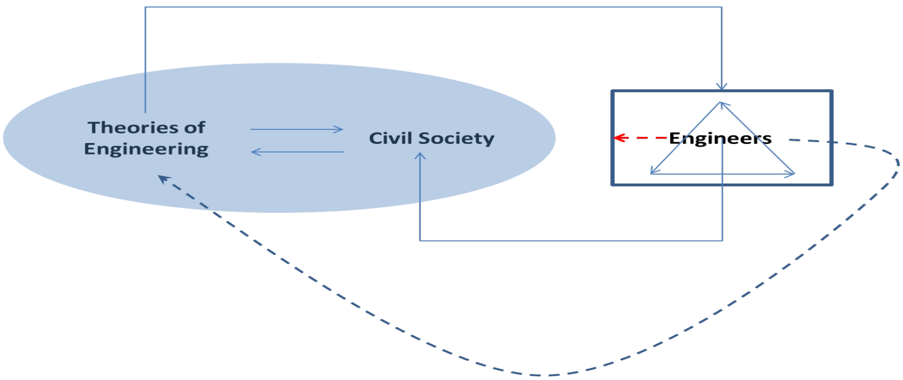
The research question in this PhD study is also a specific question, in the sense that the meaning of being a good engineer may have its Chinese characteristics, considering its cultural uniqueness. Therefore, in chapter 2, I describe the Chinese characteristic of engineering in terms of a pro-science and technology economic minded culture. Its features are extensively expressed by its environmental politics and attitudes toward nuclear power development.

In chapter 3, the influence of this broader culture to the shaping of an organizational culture is established through a historical review of the path of growth of CGN – China General Nuclear Power Group – its structure of the company, its management, and its engineering procedures.

In chapter 4 an example of how CGN engineers work in this organization culture to improve engineering design is presented. Through these findings of a participant observation, it seemed that individuals' pursuits of becoming good engineers have conflicts with the dominant culture. In this respect, the approach to answer the research question in this thesis has to take into account engineers' personal experiences.

Five CGN's engineers were invited to take part in the interviews in which their personal stories on their career development are recorded. Their views about how to improve engineering design and their personal perceptions on the relationship of their career to the notion of sustainable development are presented in chapter 5.

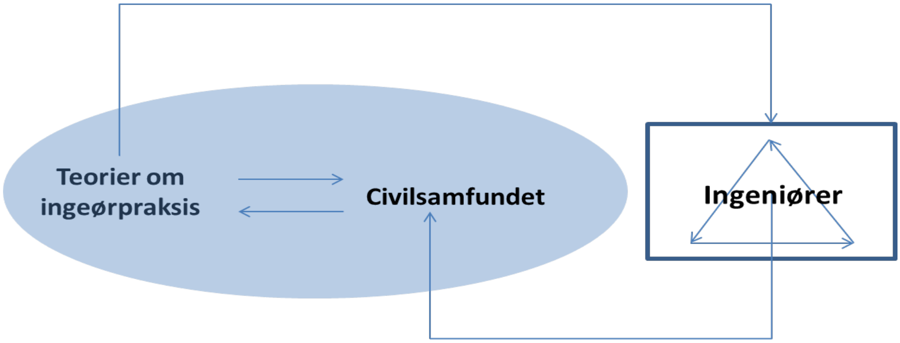
The conclusion of this thesis is based on the finding that CGN engineers tend to divide their lives with work, due to the culture filtering effects of the organization. The consequence is that it makes the evolution of engineering for a sustainable development of the society extremely difficult. Regarding to the theoretical framework of this thesis, it breaks the circulation of the loop as it can be expressed by the following diagram:



In the conclusions of the thesis I contend that in order to become a good engineer in China there needs to be opportunities to achieve a balanced self-development of the three meanings of engineering in one person, in the sense that engineers need to learn from the society and contribute to the society in a more direct manner. Perhaps what they can do now is to start by making reflections on their own experiences.

DANSK RESUME

Spørgsmålet "hvordan dannes en god ingeniør? er kompliceret, da der er mange forskellige meninger om dette og tilgange til forandring af praksis. Den "videnskabelige" eller akademiske tilgang argumenterer for en stærkere relation imellem ingeniørvidenskab og naturvidenskab. Den "økonomiske" eller tekniske tilgang understreger nødvendigheden af at styrke den økonomiske effektivitet af ingeniørens praksis. Min tilgang til spørgsmålet er baseret på en opfattelse af ingeniørens praksis som social ansvarlig. De tre meningsdannelser, som på hver sin måde forholder sig til ingeniørens praksis, kan betragtes som et lukket kredsløb, som indbefatter kulturelle dimensioner.



I kapitel 1 behandles de tre elementer, som indgår i det skitserede kredsløb. Teorier om ingeniørpraksis, som refererer til den filosofiske og metodiske tænkning i forståelsen af ingeniørpraksis. Civilsamfundet, som både refererer til et teoretisk grundlag og til et rum, hvori ingeniøren kan manifestere sig som meningsgivende. Ingeniøren er en praktiker. Derfor er ingeniører ofte positioneret i en organisation – den "sorte boks" i diagrammet. Udviklingen af ingeniører for bæredygtighed kræver en gennemgang af det viste loop. Der kan indgå forskellig aktiviteter i dette loop. I denne afhandling er der fokus på designaktiviteter, da design er et væsentligt element i ingeniørens praksis. Med henblik på at studere denne aktivitet anvendes sociologiske og antropologiske metoder, mere specifikt uføres interviews suppleret med deltagerobservation i en ingeniørvirksomhed, der arbejder inden for atomkraft.

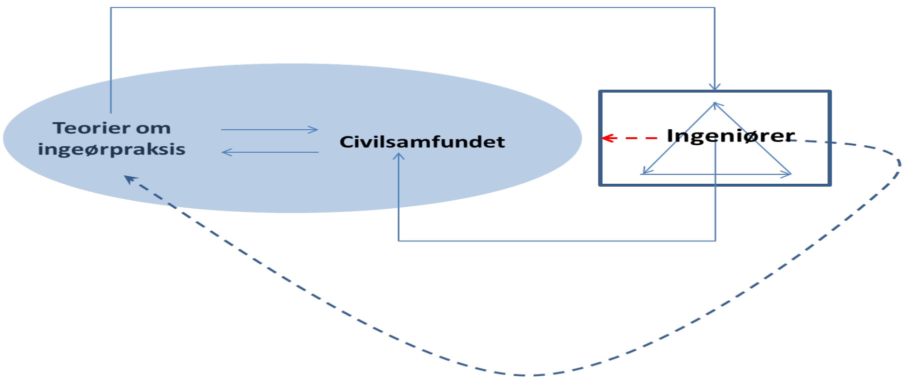
Forskningsspørgsmålet i dette Ph.d. studie er afgrænset på den måde, at meningsdannelsen omkring god ingeniørpraksis, er behandlet i en kinesisk kontekst og dermed er under indflydelse af kinesisk kultur. I kapitel 2 vil læseren derfor blive introduceret til den kinesiske tilgang til ingeniørpraksis, som en pro-videnskabelig og tekno-økonomisk kultur. Dette er intensivt behandlet i relation til miljøpolitikken samt specifikt i forhold til holdningen til atomkraft.

I kapitel 3 bliver den bredere kulturelle indflydelse relateret til organisationskulturelt niveau ved en historisk analyse af China General Nuclear Power Group (CGN), der indbefatter et blik på organisationsstrukturen, ledelsen og procedurerne for ingeniørpraksis.

I kapitel 4 gives der et eksempel på, hvordan CGN ingeniører arbejder indenfor den etablerede organisationskultur for at forbedre designprocessen. Ved deltagerobservation fremgår det, at den enkelte ingeniørs bestræbelse for at blive en god ingeniør ikke nødvendigvis er i overensstemmelse med den dominerende kultur. Derfor betragtes det som væsentligt at tage ingeniørernes personlige erfaringer med I adresseringen af spørgsmålet.

Fem CGN ingeniører blev derfor inviteret til interviews for at dele deres personlige historier relateret til deres karriereforløb. Resultatet af analyse af disse ingeniørers holdning til hvordan designprocesserne kan forbedres, samt deres opfattelser af relationen imellem deres karriereforløb og bæredygtighed, bliver præsenteret i kapitel 5.

Konklusionen af denne afhandling baserer sig på resultaterne af analysen af CGN ingeniørernes praksis, og viser en tendens til, at de opdeler deres arbejdsliv, så den organisationskulturelle påvirkning filtreres. Dette besværliggør udviklingen af ingeniørpraksis mod bæredygtighed betydeligt. På det teoretiske plan giver den empiriske undersøgelse anledning til at ændre den teoretiske ramme, da der som vist sker et brud i gennemløbet af det skitserede loop.



Til sidst konkluderes det, at for at blive en god ingeniør i Kina, skal der være muligheder for personlig udvikling, der balancerer de tre tilgange til ingeniørpraksis, så de er mulige at rumme i en og samme person. Således skal ingeniørerne have mulighed for at lære af deres samfundsmæssige interaktion og bidrage til den samfundsmæssige udviklingen på en mere direkte måde. Måske er det første skridt på vejen, at ingeniørerne begynder at reflekterer over deres personlige erfaringer.

ACKNOWLEDGEMENTS

I spend many years to learn how to become a good engineer in China. Honestly, I should say that I am not alone in this journey. A lot of people have helped me to go this far. Therefore, let me take this opportunity to express my sincere thanks to all of them.

First, I would like to thank Aalborg University and my teachers and colleagues in this university because you are the ones who have made my imaginations into this achievable academic pursuit. Here, I would like to give my special thanks to Professor Jamison for being my mentor in many ways and for many years.

Second, let me express my thanks to my engineering colleagues in China. Without your supports, inspirations, and encouragements this thesis can never be written. The book tells our stories and I hope it makes some sense.

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INTRODUCTION

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so give me reason to prove me wrong
to wash this memory clean
let the floods cross the distance in your eyes
give me reason to fill this hole
connect the space between
let it be enough to reach the truth that lies
across this new divide (Linkin Park - New Divide)

"Problem?"

"What Problem?"

This is a common conversation in our normal lives when we ask someone about a solution to a perceived problem but the respondent doesn't see it as a problem. Even though we might get an answer from the respondent, the understanding of it depends on our own reflections.

In this thesis, I try to discuss some problems and propose some solutions to them which are encountered by Chinese engineers in a real life engineering company. Admittedly, clarifying what is the problem seems to be more difficult than finding answers. Being a Chinese engineer myself, it took me about 10 years to reach a stage that I am now able to identify some of our problems and present them in a way that readers might feel that what I say makes some sense. To a large extent, my PhD research started from my experiences and observations or perhaps reflections on the real life engineering practices in China.

I was educated to be a chemical engineer through a 4 year bachelor's program, in 2003, in Nanjing University of Technology (NJUT) in China. With that degree I was not satisfied because I felt that the degree from NJUT could not bring me a high enough level of prestige. Therefore, I did not think the result corresponded to my efforts. I ascribed this feeling to NJUT's low ranking among the more than 1000 Chinese Universities. According to the newest Chinese university ranking announced by the People's Daily, my university placed somewhere between the 60th and the 70th.[1] Only the natural science disciplines in my university were scored with

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[1] Chinese University Ranking in 2015, http://edu.people.com.cn/n/2015/0602/c1053-27092223.html, (Accessed, November 12, 2015) [In Chinese]

an A while others were given Bs and Cs. But in another university ranking published by another agency which differentiated university ranking into specific disciplines that would help high school graduates' applications to universities after the competitive gaokao – the yearly national university entrance examination – the school of chemical engineering in NJUT was placed top 3[2] in China. My teachers in my school, perhaps not in the entire university, might be happy to see this unbalanced ranking because that meant the school of chemical engineering contributed too much to the general ranking of NJUT. For me, I could not be happy when I was graduated because even though in the job market, especially in the chemical industry sector, employers did appreciate the school ranking while in the academic world general ranking was more appreciated. Ironically, at that time, I was a person who wanted to become an academic researcher because, in my view, that title represented a good engineer or perhaps a real decent engineer. However, was that my fault? Did it mean that I was not smart and hardworking enough to be a good engineer? Looking into the history of my university, I calmed myself down because I realized that it was not my fault but it did have a reason.

NJUT claimed that it has a history of more than 100 years which can be traced to the early modernization period of my home country. When the nationalists took power, the nation decided to build two new modern universities in its capital Nanjing. One was called the national Jinling University and the other named the national Central University. Both of these universities together with their elderly peers such as the Peking University and the Tsinghua University served as the foundations of China's modern higher education before the socialist new China.

In the 1950s, when the socialists established a new China, education reform began to take place. In this round of reform, the national Jinling University and Central University were broken-up. The chemical engineering and applied chemistry departments in these two universities were separated and then combined to form a chemical technology college. From my perspective, in a realistic sense, that was the origin of my university. Later in the 1980s a new round of higher education reform changed the name of the college into a university – Nanjing University of Chemical Engineering – because college was standardized to refer to those higher education institutes which can only grant associate degrees while in universities bachelors, masters, and doctoral degrees can be pursued. As I can remember, up till the second year in my undergraduate education, my university was still called Nanjing University of Chemical Engineering with everything taught related to the chemical industry. There was a rumor before NJUT changed to its current status, saying that our university was going to return to Nanjing University (another derivative of the nationalists' Jinling and Central). That was a piece of good news for all of us

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[2] Chemical Engineering School Ranking 2014-2015, http://www.gaokao.com/e/20140411/5347b74a978e7.shtml, (Accessed, November 12, 2015) [In Chinese]

because all of a sudden our ranking would be more appreciated both for practical and research oriented students.

However, things did not happen as we wished. The commercialization of higher education in China started from the late 1990s triggered the university's ambition to expand its scope and scale rather than a relatively narrow minded interest in pursuing academic prestige. The result was that our university "acquired" a civil engineering college in Nanjing and shaped itself into a new comprehensive engineering university. That was my first struggle with prestige and my future.

I would not consider my concern with prestige to be an instinct. Rather, I tend to think that it was something that was nurtured or imparted. I remember quite clearly my first lecture in the university was about. It was given by Professor Shi Jun – academician of both the Chinese Academy of Science and the Academy of Engineering, a big fish in the Chinese pool of chemical engineers. He was certainly more than 80 years old by then, a PhD from MIT. He was one of the first a few Chinese students who studied in the top American engineering university when he was young in the 1930s. He told us about the history of chemical engineering and his successful time at MIT. According to him, chemical engineering as a discipline was in fact shaped at MIT. In that respect, he became one of the first chemical engineers in a global sense. Since USA is the leading country in technology development, and MIT is the best engineering university in that country his logic was that he was supposed to be the best chemical engineer in China. That was the reason why he became a professor when he was 26 in the National Central University.

What I learned from this lecture was quite clear and vivid. In the world of engineering there was no place for No.2. I must be No. 1.

In retrospect, I understand that I was not convinced by him, or more precisely, I was not able to convince myself that what Professor Shi Jun taught me was absolutely true. I gradually sensed some conflicts between my trust in technology and my hobbies.

My childhood was influenced by my father who is an experienced draftsman and mechanical engineer. It might be the reason that he wanted me to learn some more art instead of the hardcore physics, he sent me to an extra-curriculum painting course when I was a primary school pupil. In the weekends, pupils like me went together to the places of interest near Nanjing to sketch and learn how to paint natural landscapes on paper. The eastern suburb of Nanjing was where we used to go. Therefore, I was quite familiar with that area, and I loved that place because it gave me a precious time to escape from the numerous school tasks.

In the third year of my undergraduate education we were required to have an internship in a fertilizer factory. By that year we had learned almost all the core courses of chemical engineering such as advanced mathematics, organic and inorganic chemistry, engineering physics, physical chemistry, thermodynamics, analytical chemistry, unit operation, digital control, computer programing etc. The aim of the internship was to get some empirical knowledge of how these theories and methods were used in real life chemical plants. At the end of the internship we were asked to draw a flow chart and a set of engineering graphs to depict its manufacturing process. It was not a problem that I accomplished these official tasks, but I happened to encounter another problem which was not closely related to my formal engineering education.

The factory was situated in the eastern suburb of Nanjing, near an old temple which had a history of more than one thousand years. I used to know that plant when I was a child. Occasionally, when I was painting in the small hills or in the temple tried my best to depict its sculptures and buildings, I could smell some strange odor from somewhere. My mother, a chemical analyst, once told me that it was from that nitrogenous fertilizer plant. As an engineering student, I finally had a chance to take a close look at that plant and confirmed that my mother's diagnosis was correct. I questioned about the leakage of ammonia in its manufacturing process in my mind, not openly. I got a strong sense that this plant could not fit in to its surrounding natural environment at all. But it had already been there for decades. Consequently, the only critique that I could have was to its technology, dirty technology in my opinion.

This emotional antipathy to that chemical plant influenced my choices of the optional courses later in the second half of the third year and the first half of the fourth year. I took environmental technology, advanced thermodynamics and kinetics, to learn about the best technologies to be able to design a cleaner and more efficient chemical plant – petroleum chemical to be precise – in the future. At that time, I thought good chemical technologies referred to a cleaner process with less leakage and hazardous wastes and more efficient usage of raw materials. Therefore, a good engineer should be the one who can master such designs. I wanted to be an engineer of that kind.

In order to learn the most advanced technology, I decided to study abroad for my post-graduate education. This kind of a blurry decision can be traced back to some sort of a Chinese engineering tradition and the examples of my predecessors such as Professor Shi Jun – "learning from the West". My strategy of sending out my applications to foreign universities was bifurcated. But honestly, I should admit that the idea of pursuing prestige played an important role in my choices of applications. I made two serious applications with one application to the Master's program of environmental management in Aalborg University (AAU) and the other to the 5 year

PhD program of chemical engineering in the National University of Singapore (NUS).

The reason for me to apply for AAU is that Denmark is 100% a Western country, especially famous for its environmental protection. Another reason for that was that AAU encouraged students from various backgrounds to apply for its environmental management program. It was hard to imagine such a loose and comfortable requirement on undergraduate disciplines be carried out in China. If I were going to apply for a similar program in China, I was certain to face a rigid screening of my undergraduate major. Perhaps, I could not be accepted because of my chemical engineering background.

My application to NUS was due to the fact that I got a strong recommendation from our dean – an academician of the Chinese Academy of Engineering, a student of Shi Jun – who once served as a visiting scholar in NUS. Besides, more importantly, NUS's chemical engineering program has a strong cooperation with MIT. Independently, NUS is a top Asian university, certainly ahead of Tsinghua which is the best Chinese engineering university. What could I expect more? I did expect more than this because I applied specifically to its process optimization research group. In that project, I was expected to learn how to simulate chemical reaction processes via computer programing which I thought represented the future of chemical engineering. My justification for the vision derived from my observation of my father. My father switched from manual drafting to computer graphics and achieved some success in his career in the 1990s, so why should I not move a step further? In addition to that, I was a good FORTRAN programmer and to make a more precise simulation would fulfill my ambition of creating a better technological process.

It seemed that either successful application would achieve my goal of becoming a good engineer. Ironically, the real world taught me a lesson that my design for my future was just too optimistic. The fact was that I never received a letter of rejection from the NUS after the interview in Shanghai which indicated that some professors in NUS were interested in me as I was told. What I got was a letter of notification saying that my application to NUS was deferred and asked me if I wanted to wait until they made a decision. The official reason for deferring my application was not my fault as they wrote in the letter. It was in my mind rather a social problem that had struck me.

In the spring of 2003, the outbreak of the Severe Acute Respiratory Syndrome (SARS) in Asia originated from China had a tremendous impact on our daily lives. It was an environmental health problem due to the human infection of a virus from wild animals. The exposure came from eating them, as it was later proved by Chinese doctors and medical scientists. The disease spread throughout Asia. Domestically, in China, university students were grounded to the campus.

Internationally, Chinese travelers were not welcomed by its Asian neighbors during that time. I never predicted or even imagined that this incident would have its repercussions on my plans of studying abroad. But the letter from NUS clearly indicated this consequence.

I could not wait. Therefore, I thought I had lost an opportunity. I was depressed and almost wanted to give up in the days when I was protected by my university from the disease by restricting my mobility. The only belief that gave me some hope of carrying on was a Taoist saying which can be literally translated into English as “A loss, no bad thing”[3]. This saying at that time implied to me like a calling from the heaven – in the Taoist interpretation – “young man you have to be patient and good things will happen and how can you know that what would happen will be no better than what you have lost?”. Later things happened as I wished, thus it proved the relevance of Chinese ancient wisdom with a vivid example which happened to me.

I was very lucky that Denmark, and AAU accepted me and granted me a visa. Was that a coincidence? With such an experience was it implied that my life should be devoted to dealing with environmental and health problems? However, I was trained to be a chemical engineer who seems to have fewer obligations to this task.

Culture shock was tough but the most interesting and impressive experience that I gained in AAU as a master student and now as a PhD. The most direct culture shock that I encountered in AAU was its mode of education – PBL and group work. In contrast to book learning and individual written exams which corresponded to roughly 90% of my higher education in China, the AAU model of education, based on collective learning and pragmatic knowledge making, pushed me to change my old habits. Before I went to AAU, I thought I was academically well prepared to follow its courses, but cross-disciplinary learning was more difficult than I imagined. I needed to keep learning new terminologies and new methods of carrying out research when I entered into a new course. This pushed me to jump outside the box – my chemical engineering background. What made this learning socially more difficult was that it was not an individual mind changing process but a transformation immersed in a group. I had to work with my group members – none of them are chemical engineers – and I did not want to be different. In retrospect, all these challenges could not even be counted as problems until I came to my biggest problem in the second semester of my study in AAU.

This problem had become my “life project” unintentionally, and the old man – Professor Andrew Jamison – who brought it up became my supervisor ever since. He dragged me into the theory and philosophy of science and technology while firmly convincing me that I was still an engineer. How could this be realistic? That was my biggest problem. Later, I knew from his books that he might have

[3]塞翁失马，焉知非福。《淮南子・人间训》

experienced similar problems through his participation and academic interpretations of the environmental movements in the 1970s. Intellectually he was a renegade from the hardcore science – theoretical physics – to the history and philosophy of science and technology. In my experience of working with him, we perhaps never discussed the real contents of any type of science or technology, what we discussed largely was about what he called the cultural dimension of science and technology. The more I worked together with him, the more I felt that a great divide appeared in front of me – as Bruno Latour (1993) described the natural and the social divide. On one hand, I sensed that the causes of environmental problems together with their solutions might be better interpreted in social terms because technical fixes might be the origins of other lurking problems. On the other hand, I gradually felt that the identity of an engineer was slipping away from me. In order to find a solution to this problem, I adopted an escape strategy. I wanted to reshape myself to be an engineer turned sociologist. In fact, I wanted to give up my engineering identity altogether. But I couldn't. It was not only that Professor Jamison opposed my decision by telling me that I was still too young, but also that all my applications to the sociology schools for a PhD study failed in 2005, the year I graduated from the master's program. Before I left Denmark, I had a talk with Jamison. He tried to convince me that I would be better off to continue with my engineering career and it looked as if AAU would also support that because I got a Master of Science degree in Engineering which I thought could not be the case in China. I thanked him and AAU but I did not ask the deeper question that confused me: you changed me into half an engineer and an amateur social historian of science and technology which was quite interesting but so what? Could I make a living with that?

I left AAU in 2005 with this confusion, but I quickly forgot about it. I needed to find a job to be independent. It only took me a few days to get a job which many of my peers in China would think was very exciting. I was employed by Jiangsu Foreign Trade Corporation (JSFT) which was a state-owned enterprise run by the provincial government. In the first few months of this job, I was sent to the business school of Nanjing University to receive some training in international commerce and finance. It was just mathematics, not a difficult task for me. My first real job in that company was to act as an engineer for one of its overseas investment projects. It was an industrial park project in India. I was asked to work with a civil engineering design institute to make a blue-print for this industrial park and I was also involved in the advertisement activities to attract Chinese manufactures to establish new plants in this industrial park to be built for them. But later I found the real intentions behind this project, the real "design". On the surface, it was a project to help Chinese manufacturers to establish their production facilities in India but in fact it was a project that would reduce JSFT's cost of business expansion. JSFT had a long history of importing iron ore from India to support the great demand of that raw material from China's booming steel industry. Therefore, JSFT always wanted to have its own port and a more direct connection to the mining sites in that country. If an industrial park can be built there, a port can be included and its development investment can be indirectly reimbursed by the rentals paid by those smaller manufactures that just intended to use some limited piece of land in a shorter period of time. In addition to that, building an industrial park instead of a straightforward intention of building a port would gain more support from Indian local government. What's more important was that such a big project would attract long-term low interest loans from the Chinese government owned banks. After realizing this fact, it made me feel disappointed because compared to my financing colleagues, my task of studying Indian industrial development regulations seemed to be very superficial.

Another relatively concrete engineering task that I worked on for JSFT was a project of investment in the Philippines for a nickel mining site. This project taught me a vivid lesson of how environmental concerns were misused for the purpose of business. Nickel ore is a much more expensive raw material than iron ore especially taking into consideration its chemical processing. The current commonly used chemical enrichment process to produce pure nickel was from its sulfide but even though that kind of ore has higher nickel content, its existence in the earth is too rare compared to its oxide. But Chinese engineers developed a way to use the more abundant nickel oxide to make not pure nickel but a nickel iron alloy which can still be used to produce stainless steel. At the beginning this technology seemed to be more environmentally friendly because less sulfide waste would be produced. But the real question is that it might not be the case because in order to get the same amount of nickel more coke will be used to burn the nickel oxide ores – normal rocks and red earth – into ashes so that the metallic content can be further enriched. In fact, in most situations it is a more environmentally dangerous technology. In the years from 2006 to 2008 when the price of pure nickel in the London metal exchange market reached its historical peak any cost to get more nickel from the earth seemed to be worth the cost.

In 2007, I was first sent to the Chinese plants to gain some superficial knowledge about the manufacturing process and then directly sent to a mining site in the Philippines. This time, I was not only an engineer but a project manager. I was in charge of the negotiation between JSFT and a local landlord who had already sold the earth from his mountain to Chinese and Japanese buyers. My task was quite clear. I needed to justify whether that earth would be lucrative if we shipped it to the Chinese port. I witnessed how the miners used ancient technology to make diesels to fill their excavators on site which could be harmful for their health and the environment. Together with the landlord I met the mayor and even talked a little bit about environmental protection which is certainly not the major topic. I knew, in that situation the only useful engineering knowledge at hand was analytical chemistry. No matter what we had talked and discussed, my argument to JSFT should be constructed on some sheer scientific basis, a report of the content of nickel from a trustworthy machine.

After all those years, I did not find the answer to my question which had emerged in 2005, and what made it even worse was that I seemed to be more distant from my initial aim of becoming a good engineer than when I left China for Denmark. I wanted to change jobs because I felt that my role in JSFT was to serve economic interests, and that "engineer" was just a title, and the substantial work that I had done was in fact what a merchant would do. Even though I did not know how to be a good engineer yet, I did know why I was getting away from it. The first reason was that the company was in fact a pure money making operation, and the second reason could be that as an engineer I was used as an instrument. To change this situation I needed to perform some original design of an instrument but not acting like one. That was one reason for me to leave that company.

In late 2008, I got an offer from China Nuclear Power Engineering Company (CNPEC) in Shenzhen. I accepted this offer with a condition that I raised to the company saying that I would not work and live on the construction sites. I had just gotten married. Therefore, I became an engineer who worked mainly in the office with occasional short term travel to the site. In general, I should appreciate CNPEC for this opportunity because it gave me a sense of "safety"[4] that I wanted at that time. This sense of "safety" derived from several aspects. Economically, CGN (China General Nuclear Power Group, the mother company of CNPEC) as a company owned by the central government has much stronger financial power to ensure a stable income. In 2008 when the financial crisis originating from Wall Street hit China, JSFT as a trader was heavily influenced. But CGN seemed to benefit from that crisis. In this respect, stability became an advantage. Professionally, in an engineering company like this, it seemed that my engineering degree would be more appreciated. Thirdly, in terms of prestige, I was about to work for its Taishan EPR project, one of the newest types of nuclear power plants and the biggest in terms of capacity in the world. I felt honored to be a part of this contemporary engineering feat in China.

Honestly, I did think about nuclear power as a risky technology, but I was convinced by the anonymous interviewer who later became my boss when I suddenly saw him welcome me to my desk on the first day of my arrival that I had no chance of being exposed to radioactive substances in my work. Besides, he gave me a first lesson on the intrinsic safety of nuclear power plants. In the interview, the longer the time he spent on this lecture, the higher the chance I thought that I might be offered. Being a

[4] The Chinese translations for safety and security are the same 安全. Oxford Advanced Learner's English-Chinese Dictionary (Eighth edition) published by the Commercial Press in China and the Oxford University Press in UK. (2014) In nuclear power engineering safety or safe is widely used both in Chinese and in English, so in this thesis, in order to represent the vocabularies of Chinese nuclear power engineers I use safe to replace secure in some occasions.

chemical engineer and a young business-man, in 2008, I thought I learned a “truth” of life: everything is risky, so why not take this risk?

Between 2009 and 2011, I almost forgot the question that had occupied me for years. Perhaps it was due to the fact that I finally found my way of becoming an engineer in a prestigious company in China, or it could be the change of my social identity that I became a father. Everything went well, and the booming development of Chinese nuclear power seemed like it could not be interrupted. Every day, I was brain-washed by the benefits that we could get from this technology, and personally, I might be a benefactor as well. I did not even want to criticize nuclear power technology. If somebody asked me about the problem of nuclear power, I would answer him or her with “what problem”. But nobody asked me such questions during that period of time.

This happy hour did not last long. The Fukushima accident changed a lot of things. My old friends began to ask me safety questions about our nuclear power plants, and our central government stopped granting construction permissions to new plants. Some senior engineers in our company who had experienced the cold winter of nuclear power in the 1990s in China began to worry about their safe retirement. This kind of pessimistic anticipation influenced me because I had just began to be accustomed to a stable life and felt reluctant to make any changes. But I got a feeling that perhaps it was time to be prepared to change again. One evident change that I experienced in late 2011 and early 2012 was that I was not that fully loaded with work as before.

It was in these circumstances that I started to think about the old question again. I first would like to provide an answer by myself, based on my own experience; therefore, I tried to write a novel in English. I sent the first half of the novel to Professor Jamison because I thought he was the one who might understand me and give me some comments. I always thought of him as the person who taught me – an engineer – to criticize technology from a social perspective which seemed to be quite ironic. But as long as he was the one who brought it up, he might also be the one to work it out. For that reason, I met him in Copenhagen in spring 2012 on a Sunday, in my free time before a meeting with AREVA NP in Paris. We only had a short meeting, because I had booked a return flight to Paris a few hours later.

Our conversation was, to some extent, beyond my expectations, because it was in that 2 hours talk he transformed my “life project” into a PhD project, a part-time PhD project in Aalborg University. He suggested to me to read his writing about hybrid imagination – a concept that he had recently developed. At that time, I felt like I was very close to a “truth”, and I decided to carry on. Another suggestion given by him strengthened my decision in that it made me think such a research was methodologically feasible. I remember he said: “try to make your memory a collective memory not something solely about yourself.”

In the meantime, the company seemed to be more anxious than I was. For me it was just a possibility of changing jobs. But for the company, it was a matter of life and death. In 2012 rumors began to be heard by Chinese engineers from the colleagues employed by AREVA NP saying that AREVA was facing extreme difficulties in its OL3 EPR project in Finland. Nuclear power developments in its home country – USA – were also not clear at all. The Westinghouse AP1000 units were only built in China, but the US government was not in a hurry to put them into real construction on its own land. Privately, we had a lot of doubts about this situation. Behind these guesses a common point of departure was a worry about the future of nuclear power.

The company could not and would not oppose nuclear power, but it also had to think about how to make a living for its employees. Therefore, the company started a program in the name of a reform to get some business other than nuclear power because the company leaders thought engineering was a universal capability. As long as we can make nuclear power plants which are deemed technologically more complicated, it is highly likely that we can make other machines and constructions. A lot of engineers supported this judgement for various reasons; therefore, on one hand a new round of engineering capacity building programs or campaigns were triggered in this company since 2012. On the other hand, the marketing development department began to search for new opportunities for the survival of this company instead of waiting for an order of constructing new nuclear power plants.

I took this opportunity to get a closer observation of my colleagues on what they think a good engineer can be. I focused not only on their opinions but also on their experiences on which their opinions were based. I tried to immerse my personal stories into these collective stories, to be a participatory observer instead of a pure audience. As such I hoped my initial problem of becoming a good engineer could be answered, not through limited personal reflections on my past but from storytelling of some collective experiences.

In this thesis I do not try to theorize our stories, or generalize from them with statistical confidence, so that the engineering readers can learn from my “successful past”. Rather I reflect on our memories and by doing so I mean to help my readers to understand that our living experiences count.

CHAPTER 1. THEORIES AND METHODS

The title of this thesis is "A Book of Changes in Engineering: On becoming a good engineer in China". Therefore, the research question is how to become good engineers. However, from my experiences and observations, I recognize that the focus of this question may vary from time to time in one person and in different individuals. This gives me a reason why I indicate the study of it shall be focused on changes. But a change of what? and how? In this chapter, I try to answer the "what" question by presenting my literature study in section 1. I postpone the "how" question to the following chapters by giving some examples.

In section 2 of this chapter, I write about the methodologies used in this PhD research, and in section 3 the process of this research is illustrated to demonstrate how the chosen research methods were adopted.

1.1. QUESTIONS AND ANSWERS ABOUT ENGINEERING AND ENGINEERS

To answer the question of what needs to be changed, I think, we need to address issues both inside and outside the engineering world. Firstly, we need to understand what kind of jobs engineers are performing. In other words, this aspect refers to what engineering is about. Secondly, it is important to look into engineers' practices, so that we might understand the concretization of different perceptions of engineering in real life engineering practices in a company or particularly in a project. Thirdly, we also need to identify what are the relationships between engineering and other human activities or we need to depict the interactions of engineers with other members in the society. As such we might point out something that needs to be changed from the perspectives that derived outside the engineering world.

These three aspects cover a wide range of academic studies about engineering and its practitioners; for example, the philosophy of science and technology, the sociology of science and technology and technology management and innovation studies. In all these fields, it is hard for me to distinguish what views derived from inside and what emerged from outside the engineering world. On top of that, it is also difficult to interpret engineering practices without a combination of the three aspects, for example engineering design. The engineering design process resembles different perceptions of engineering and the evolution of the traditional design approach to the innovative design approach incorporates more social elements into it. Therefore, instead of using the inside and outside demarcation as the logic of analysis, I would rather adopt a combination approach by responding directly to the questions raised by both academics and engineers. Such an approach of combination was inspired by Newberry (2009) as he put it:

> "that engineering is an activity that ought to be studied and understood, in no small part because of its critical role in the creation of modern technology, technology which we know has transformational power for both the natural and social structures of our world. But engineering is not some external agent exerting its influence from the outside. It is endogenous to the world upon which it acts. It is an emergent process that coevolves with, and is inseparable from its medium." (Newberry, 2009, p.33)

At the end of this section I try to "translate" academic questions with real life engineering vocabularies used in the company where my observation was performed, as such a connection between theory and practice might be established.

The following seven questions appeared to be the common concerns of both the academic studies and CGN engineers:

1. What distinguishes engineers from technicians?
2. What are the relationships between engineering and science?
3. What are the different meanings of engineering?
4. What are engineering designs and their processes?
5. Why did engineering become a "weak profession"?
6. What are the national characteristics of engineering?
7. What is the relationship between culture and engineering?

1.1.1. WHAT DISTINGUISHES ENGINEERS FROM TECHNICIANS?

What are the differences between engineers and craftsmen? Are the well-educated workers on the shop-floor who make or fix machines engineers? Is a nuclear power plant operator in the main control room an engineer? These questions are often discussed among engineering professionals for a pragmatic reason – the division of labor. Even though we know that the making of technical artifacts served as the theme of engineering in which people who design, produce, and operate them are all involved, different roles among them are also quite evident. Due to a negative perception of the phrase "division of labor" which is the basis of scientific management in which humans are treated like machines (Mumford, 1970) it seemed that such questions are often answered in a more philosophical sense. Considering that the making of the knowledge on how to make technical artifacts and the physical works of manufacturing or constructing them are two different types of practices, the practitioners can be differentiated. As Kores (2012) put it:

> "The definition suggests that the making of a technical artefact involves two steps, one involving mental and the other physical activity, and that these steps may be performed independently of each other and may therefore be separated in time. Each step has its own success criterion; the first mental step is successful if it produces a largely correct design and the following physical step is successful if it comes up with a physical object that is a largely correct execution of that design." (Kores, 2012, p. 128)

Accepting this distinction between the mental and physical processes in the making of technical artifacts and appreciating the mental process of a higher value the distinction of engineers among their subordinates can be briefed as the following:

> "Design is perceived as a key differentiating activity that separates the engineer from the engineering technologist." (Murphy et al., 2015, p.41)

My understanding of the above quotation is that engineers are those who perform engineering designs while the rest of the participants in the making of artifacts are not engineers as they are defined by Murphy et al. (2015). In this respect, to be a good engineer can be interpreted as to improve his or her designs. Thus, engineering design becomes the major topic of this thesis.

From a socio-historical perspective, the shaping of the contemporary engineering identities such as the emphasis on knowledge making rather than the manual input to build them held its root in the industrial revolution in the 1800s in the West. In that period of time, professional engineers began to stand out from their processors – craftsmen. This transformation as Hård and Jamison (2005) depicted was largely due to the assimilation of scientific knowledge:

> "By means of systematic experimentation, for instance, craftsmen – in cooperation with men of science and not seldom supported by the state – could make the traditional techniques of energy production, mining and metallurgy, and manufacturing and agriculture more efficient. With the help of mathematical reasoning, new kinds of regulation and management could be developed, and mechanical models could provide much greater degree of precision and possibilities for control over normal processes of primary and secondary production." (Hård and Jamison, 2005, p. 53)

This transformation of knowledge based production of technical artifacts has not stopped. As Hård and Jamison (2005) put it:

> "The industrial transformation did not end, of course, with the turn of the century. In many respects, its discourses, institutions, and practices are still very much alive in the early twenty-first century. On the discursive level, the language of science-based progress still dominates contemporary thought … …" (Hård and Jamison, 2005, p. 53)

What we have witnessed today is perhaps an even more science based engineering than ever before, in the sense that after the transformation from craftsmen to engineers it might be a time that engineers turned themselves to be men of science in the recent decades of technoscience. As Jamison et al. (2011) put it:

> "At the same time as the computer revolution was taking place, other developments in science and technology, especially in molecular biology and genetics, were bringing the worlds of scientific theory into more intimate contact with engineering and technological development. Genetic engineering and the other so-called biotechnologies were among the first 'technosciences' that would emerge in the coming decades. By mixing previously separated fields of knowledge into new combinations, these fields challenged both the traditional identities of scientists and engineers but also the traditional ways in which they were educated." (Jamison et al., 2011)

In these circumstances, it seemed quite convincing that contemporary engineering design is more and more relied on the abstraction and idealization of real life objects to established scientific models. (Pedersen, 2015) But a question emerged: are engineering and science the same? If they are the same, why the studies of the engineering design methodologies become an independent area from scientific research methodologies? With these considerations, the second question listed in this chapter seemed to be quite important for the understanding of engineering and engineers.

1.1.2. WHAT ARE THE RELATIONSHIPS BETWEEN ENGINEERING AND SCIENCE?

Science and technology are interrelated knowledge. Looking at the object of the scientific and technological studies, non-humans appeared to be the common domain on which both science and technology are targeted. However, the subjects who make such knowledge are common as well, humans. Taking these common practitioners of knowledge making into consideration, both of these types of knowledge can be interpreted as social constructs. (Pinch and Bijker, 1984)

Due to the fact that science is normally considered as the discovery of natural world, and technology is regarded as the making of artifacts, a question emerged. Is technology a derivative of science or its application?

A positive answer to this question can be found in the interpretation of the social status of engineers. As Christensen et al. (2009) put it:

> "Intellectually engineering has been subordinated to science. Socially engineering practice has been subordinated to a managerial agenda driven by the market." (Christensen et al., 2009, p. 14)

Perceiving the core engineering practice – design – as an individual mind process, the notion that engineering stands at the lower level of science become more evident, as Kroes (2012) put it:

> "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation." (Kroes, 2012, p. 131)

These quotations not only provide some seemingly definitive answers to the question regarding to the relationships of science and technology but also point out the relationships of science technology with the society. According to these theories, humans learn to make technical artifacts by using natural resources. Therefore, it is a prerequisite that before making them it is necessary to know the physical and chemical properties of the natural resources to be used. Knowing such properties happened to be the tasks of science. In this respect, science became the prerequisite of engineering. An implication of this reasoning is the division of human and non-human, the subject and the object but the falsification of this divide may lead to another interpretation of the relationships between science and technology and perhaps the relationships among science technology and the society.

Bruno Latour is the one who questioned the divide of subjects and objects, nature and culture. According to him the so called objects of scientific and technological knowledge is not pure objects but some Quasi-objects, as he put it:

> "Society is neither that strong nor that weak; objects are neither that weak nor that strong. The double positions of objects and society had to be entirely rethought. … …Linking the two poles of nature and society by as many arrows and feedback loops as one wishes does not relocate the quasi-objects or quasi-subjects that I want to take account. … …Quasi-objects are in between and below the two poles, at the very place around which dualism and dialectics had turned endlessly without being able to come to terms with them. … … Quasi-objects are much more social, much more fabricated, much more collective than the

> ‘hard’ parts of nature, but they are in no way the arbitrary receptacles of a full-fledged society. On the other hand, they are much more real, non-human objective than those shapeless screens on which society – for unknown reasons – needed to be projected.” (Latour, 1993, p.55)

Latour’s theory of science and technology left two implications. On one hand, he indicated a combination of science and technology, such as Jamison’s identification of “technosciences”. On the other hand, it also implied that science and technology shall not be studied without an incorporation of their intrinsic social elements. As I understood, the social construction of science and technology, and Newberry’s study about engineering are in line with this perception. This kind of a “hybrid” perception of science technology and the society may lead to another perception of engineering as Jamison portrayed:

> “This third kind of engineering takes place in very different contexts or social locations than the other two, often in what are characterized as social and cultural movements rather than in established or formalized institutions and organizations. Understanding these contexts of engineering brings out the ambivalence, or mixed meanings of science and technology in human history, and the ways in which engineering has often had to be carried out at the ‘grass-roots’ in informal and temporary public spaces, in order to provide alternatives to the dominant approaches.” (Jamison, 2009, p. 59)

What can be read from this quotation is that science and technology may be different, but they can all be used as means to solve problems. Since it is hard to diagnose whether a problem is purely natural or social, engineers’ direct responses to the problem may mobilize all kinds of knowledge. What seemed to be evident to me is that according to Jamison, a hierarchy does not necessarily exist between science and technology.

Discussing the relationships of science and technology and their dynamics with the society, three different meanings of engineering become clear, in the sense that engineering might have its scientific meaning, its commercial meaning and its broader social meaning[5]. In the following sections, I will elaborate what these meanings refer to and how they influenced the most important engineering practice – engineering design.

1.1.3. WHAT ARE THE DIFFERENT MEANINGS OF ENGINEERING?

Jamison et al. (2011) has portrayed three contemporary orientations of channeling engineering practices through an overview of each of its historical origins. The

[5] In the later sections and chapters I name it human meaning.

dominant approach of guiding engineering is a hubristic commercialization strategy which focuses on technological innovations. In contrast, a residual strategy which seems to reject commercialization can still be seen, namely, a professionalization approach which tries to defend the scientific nature of engineering. But, Jamison would not think that these two strategies represent the future of engineering. For he thought, following either of these two ways, engineering might deviate from its authentic destination of enhancing human life[6] in the sense that engineers may lose many opportunities if they are not thinking challenges as opportunities. Therefore, Jamison searched for a third way of engineering neither in the world of commercialization nor professionalization but somewhere in the middle. His ideal type of engineers can be termed as green engineers with hybrid imaginations which can be elaborated as:

> "A hybrid imagination can be defined as the combination of a scientific-technical problem solving competence with an understanding of the problems that needed to be solved. It is a mixing of scientific knowledge and technical skills with what might be termed cultural empathy, that is, an interest in reflecting on the cultural implications of science and technology in general and one's own contribution as a scientist or engineering in particular. A hybrid imagination involves recognizing the limits to what we as a species and as individuals can do, both physical limits and constraints imposed by 'reality' as well as those stemming from our own individual limits of capabilities and knowledge." (Jamison, 2013, p. 17)

In fact, Jamison is not the only one to raise questions to the commercial and professional strategies of engineering. Newberry (2015) questioned the pursuit of efficiency in engineering, as he put it:

> "Efficiency has to do with avoiding unnecessary time and effort, with not being wasteful, with getting things done in a clever and intelligent way, and with saving energy. But these commonplaces notwithstanding, efficiency is an elusive concept." (Newberry, 2015, p. 201)

Despite of the diverse definitions of efficiency in the engineering world, real life practice to achieve it can often be ironic in the sense that in order to reach other engineering goals such as safety and multiple utility, the fundamental concepts of efficiency such as the optimal consumption of natural resources can be sacrificed. As a result, efficiency becomes a constraint that needed to be conquered and engineers like to conquer limits.

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[6] For Dewey, engineering is ultimately and properly subordinate to the enhancement of life and the qualitative enlargement of human experience. (Christensen, et al. 2015, p.xxii)

Pedersen (2015) questioned the over-abstraction of engineering model making.

> "This work requires comprehensive abstraction and idealization, and, as a consequence of that, advanced mathematical and physical theories are only valid in highly abstract and isolated systems. Consequently, these theories are far away from the concrete contexts that engineering design is about." (Pedersen, 2015 p. 179)

The gap between scientific theories which are only valid in isolated and purified systems and engineering concretization of ideas in reality leads to a deep epistemological question of engineering design – how far are we close to reality if we are going to construct man-made objects on our idealization which is in fact far away from reality? As far as I am concerned, this epistemological problem leads to two real life engineering problems. On one hand, it indicated the reason why so many sites' problems still occur when the complete set of design documents have already been issued. On the other hand, the dependence of abstraction in science has been appropriated by engineers to communicate with the society. Perhaps it is due to the convenience of abstracting society to economic models and predictions, to reduce humans to economic legal persons, that the commercialization of engineering is so dominantly adopted by engineers. From the point of view of the social construction of technology, it might be sufficient to argue that it is enough because enhancing human life can be interpreted as fulfilling our needs materially.

To some extent, the scientific and commercial meaning of engineering can be compatible with each other, provided that society is manifested as the market. What differentiate the social meaning of engineering in a broader sense to the commercial meaning is that the notion of civil society contains much less economic features than the market. However, according to Jamison (2009) it happened to be the site on which many engineering practices were carried out. In order to differentiate this broader social meaning of engineering to its commercial abbreviation, I call it the human meaning of engineering in this thesis. The intention of doing so is that engineers shall also be counted as a member of the civil society as they are indicated by Jamison. As a consequence of incorporating engineers into the civil society, what I mean the communication between engineers and the society indicate more meaning than just a promoting of their products to the clients.

1.1.4. WHAT ARE ENGINEERING DESIGNS AND THEIR PROCESSES?

According to the quotation of Kroes (2012) in section 1.1.2 of this thesis, engineering design is a process. But what kind of a process is it? The traditional engineering design methodology tends to think it as a production process based on scientific knowledge and reasoning. The social approach considered it as a consensus reaching social interaction within a design organization. The innovative approach described it as a R&D process of making novel technical products.

Underneath these diversified interpretations of engineering design and its processes, the influence of the different perceptions of engineering discussed in the previous section seems to be obvious.

The traditional school of engineering design studies represented by the Paul and Beitz's Systematic Design (2007) did not distinguish the engineering design of an artifact and a socio-technical system. Although in the later version of Paul and Beitz's publication they did advice engineers to pay more attention to customers' demands, their system of engineering design is still a simplified model of real life design to which equals a production of a set of manufacturing documents. This simplification makes their methodology consistent with the project management customs of modern engineering which in fact addresses a scientific management philosophy. The advantage of this simplification is that their methods can be widely adopted for both the design of an artifact and a socio-technical system, because engineering design is treated as purely a scientific reasoning matter in which technology is independent from its social settings.

Bucciarelli (1996) questioned this over simplification of the iteratively linear process of engineering design by postulating that real life engineering design should be considered as an ad-hoc social process. What Bucciarelli found through his participant observation from American engineering companies were that interactions between different engineering disciplines – object worlds in his original words – permeated the entire design process and it seemed that the sequence of events and activities could never be predicted. Bucciarelli did reveal the internal communication inside the design organization but he did not address enough the external communications of engineers with the society. As Vermass (2015) pointed out:

> "This propagated multidisciplinarity goes beyond the multidisciplinarity in design as analyzed by Louis Bucciarelli (1996)". (Vermass, 2015, p.154)

This meant that the socialization of engineers in Bucciarelli's findings was still restricted to the engineering world and it also implied that if external communications were about to carry out perhaps a new "object world" needed to be recruited – social scientists.

A new school of engineering design methods can be termed as innovative designs which were inspired by the commercially successful stories of ICT technologies. This type of engineering design practice is based on a prediction of needs. Compared to the traditional school and Bucciarelli's perception of object worlds, this innovative designer driven design extend its process from solely providing a product solution to a need formulation. As such, on one hand, it is difficult to segment engineering design into linear phases as conceptual design, embodiment design and detailed design; on the other hand, some traditionally non-engineering disciplines are incorporated in the design process. According to Vermass (2015):

> "Due to the development of design methodology, engineers are thus nowadays sharing the control over design with other agents by collaborating with those agents in formulating needs and design problems, and in finding their solutions. In fact, in current methods the agents involved in design practices are not called engineers but have labels like 'product designer', 'industrial designer', or simply 'designer'. Engineering is no longer the only discipline involved in current design, and may in a grimmer scenario actually end up being confined to only particular parts of design." (Vermass, 2015, p. 155)

In a rigid sense, it might be a waste of time to discuss whether the society expressed a need – an intention – first or the customers were intrigued by designers' novel ideas. What matters in this type of design is in fact its commercial viability. Consequently, a fear of engineers losing their identity appeared. As Vermass (2015) said:

> "Yet engineers also have to share this position with designers from disciplines other than engineering, and engineers may even lose their new role… … Engineers will in that case be forced back into their assistant role and become suppliers of technical solutions to other designers." (Vermass, 2015, p. 147)

In addition to some consensus with Vermass, I have some other interpretations on his findings. First, I am convinced by his notion that external communication with the society do exist in real life engineering designs even for the more traditional engineering projects such as the nuclear power[7]. Secondly, in this process, social scientists, legal professionals, and people from other disciplines do involve. But thirdly, I am not convinced by his static views on the identity of engineers because in real life people can and may change. In my observation, I witnessed numbers of engineers turned managers, business developers. Therefore, instead of sticking to the traditional definition of engineers, is that possible that we think engineering is in fact an elastic, changing and quite adaptive profession? Anyway, in the dominant commercial environment, it might be true that becoming an engineer turned business planner or developer or even a hybrid of these two domains could represent a successful orientation. But, what other types of transformations, adaptations, and hybridizations – in summery changes – can engineers take?

[7] The preliminary construction application and the environmental impact assessment and their public hearing can be deemed as a form of external communication in the case of nuclear power engineering.

With these questions, I noticed a missing position in the design methodologies in the sense that the human meaning of engineering seemed to have no influence on the development of engineering design methodology. The reason for this missing theory is – as Jamison (2009) put it:

> “This meaning has been given far less attention than the other two, due perhaps to its intrinsic diversity and variety, as well as to what might be called its ‘situatedness’ or particularity; it is hard to aggregate or theorize about these forms of engineering, but they are nonetheless of central importance for many areas of human existence, particularly in relation to education and health care and environmental protection.” (Jamison, 2009, p. 51)

For these reasons, I cannot depict the process of a human centric engineering design or even to define what a human centric engineering design is. However, what I am inspired by this interpretation of the human meaning of engineering is that the human meaning of engineering might be reflected more evidently in certain discourses such as the environmental discourse or sustainable development. On top of that, these discourses normally contain some critical thinking of science and technology which I found extremely lacking inside the engineering world from my observations. It might be ironic to ask engineers to criticize their own work, as if they were criticizing themselves. But this irony seems not to be the fundamental reason for engineers’ reluctance to express this meaning of engineering in practice. What seems to be the reason is the impression of engineering as a “weak profession” which indicates less social power. In this respect, the cultural or social critique of science and technology seems to be remote from engineering professionals; however, it should not be the case. This impression needs to be changed especially for engineers themselves. In the following section let me first describe how this impression was shaped.

1.1.5. WHY DID ENGINEERING BECOME A “WEAK PROFESSION”?

Based on the American experiences, compared to other professions, engineering seemed to be a less unified occupation. This perception of engineering can be reflected in three aspects. First, it seemed that on one hand engineers do all kinds of jobs related to the construction and making of material objects anonymously. On the other hand, the end-users of certain technologies even do not know who made them. For example, in nuclear power engineering even if the customers know which company build the nuclear power plant, the technology itself was not entitled by certain engineers personally. This induced a public perception that engineers are everywhere because it is difficult for the outsiders to give an expression of what exactly they are doing even regardless of the concealment of technical knowledge. Newberry (2015) wrote it:

> "When surveyed, people often correctly associate engineers with the production of certain iconic technologies – such as vehicles, bridges, spacecraft, computers, and electronics. But those same surveys indicate that people do not know much about what engineers actually do." (Newberry, 2015, p. 11)

Secondly, within the professional world of engineering, different objects worlds shaped different types of engineering work. In plain words, a chemical engineer is certainly different from an electrical engineer in that chemical engineers lived and worked in the world of molecules while electrical engineers deal with electrons. This indicated different objects of design and methods of working. Therefore, pragmatically, it is hard to formulate a general discipline at the appropriate level of abstraction, a formal set of qualifications and ideals and obligations for all the practitioners even for the same technical system such as nuclear power engineering. Newberry (2015) had made the following statement:

> "In short, a profession comprises practitioners of a discipline having a formal, shared set of qualifications, ideals and obligations. But engineering's status as a profession is complicated. Much of that complication is due to the staggering diversity of engineering disciplines and occupations." (Newberry, 2015, p. 12)

Thirdly, in respect to career development, the higher the ranking of an engineer in an organization – normally within an engineering company – the less concrete technical tasks the engineer tends to be assigned in his daily routines. On the contrary, non-technical contents – for instance business and management matters – consume a greater proportion of his or her energy and time. In that sense, engineers themselves are often confused with the demarcation of the technical and non-technical tasks. Newberry (2015) discovered the following phenomenon:

> "The low level engineer will certainly be cognizant of the importance of budgets, deadlines, and other business objectives, but will typically engage them only in fairly abstract ways. The technical issues, on the other hand, are very concrete for that engineer." (Newberry, 2015, p. 14)

All these features of engineering practices give engineers an illusion that they are always doing what they are told to do. Therefore, it made them reluctant to be reflective intellectually and socially of the technology they have been made because their roles seem to be instrumental and consequently, their minds became instrumentally pragmatic. Newberry (2015) summarized his findings as such:

> "Earlier we mentioned that engineers are sometimes accused of being unreflective with respect to the broader implications of their work. It should be no wonder that people who are constantly engaged in the solution of concrete, particular, and finite problems, and who habituate

> themselves to solution methods that discretize and simplify those problems, are not as a rule always and instinctively cognizant of the more abstract and potentially generalized effects of those solutions." (Newberry, 2015, p. 20)

The instrumental roles of engineers had another socially imbedded origin, in that, unlike lawyers and medical doctors who are mostly self-employed, at least in the United States, engineers are typically employed by private companies. As Downey et al. (2015) stated:

> "that engineers in the U.S. are mostly not self-employed professionals, in contrast with physicians and lawyers, but employees of larger firms that benefit from engineering fragmentation. The individual engineer is typically not an autonomous or consulting engineer but one whose professional identity is defined in terms of the economic interests of private industry." (Downey, et al. 2015, p. 83)

In this respect, it might be true that improving our technical knowledge might be an activity for the benefit of all human beings in general. But in real life practices such activities are often more directly related to the interests of engineers' employers. It looked as if the companies which provide engineers with chances of making a living but also at the same time restrict them from interacting with the society in which they also belong to. Historically, the transformation of civil men into organizational men had long been identified by American social philosophers like Lewis Mumford (1970).

Although, it seemed that there had been a long lasting tradition to counter this transformation, engineers' appearance in these activities seemed to be invisible. On one hand, engineers felt that they were socially less powered; on the other hand, dealing with social problems might not be in the realm of their expertise.

In fact studying the social identities and roles or more bluntly social status of engineers has become a core issue in the ethics of engineering throughout the world. According to Mitcham et al. (2015), after the 1970s, the American approach of engineering ethics was quite influential. It might indicate that why the abovementioned views about engineers' positions in society, in companies served as to some extent a common sense among engineers throughout the world. But admittedly, engineering work is often quite specific. This might lead to some regional characteristics of engineering and various interpretations of engineers' social identities.

1.1.6. WHAT ARE THE NATIONAL CHARACTERISTICS OF ENGINEERING?

In this thesis, the national characteristics of engineering referred to the different perceptions of engineers' social status in society in different countries. According to Downey et al. (2015) and Mitcham et al. (2015) the establishment and transformation of engineers' social status in some industrialized countries relied heavily on its social history.

In America, the professionalization of engineering can be seen as a long lasting struggle of engineers to achieve professional unity and autonomy. (Downey et al., 2015 and Mitcham et al., 2015)

> "The engineering profession in the United States has been a world leader in promoting engineering ethics code development and associated educational activities. But this leadership has grown out of a long, and continuing, struggle and desire for professional unity and autonomy." (Downey et al., 2015, p. 85)

The introspection of what engineers did in the Second World War by reiterating professional work shall be subject to the service of humanity respect to human dignity represented the contemporary motif of German engineering identity. (Downey et al., 2015 and Mitcham et al., 2015) As Downey et al. (2015) put it:

> "To include an explicit commitment to humanity as a whole constituted a self-criticism by German engineers, who previously had understood themselves as advancing civilization by serving Germany." (Downey et al., 2015, p. 92)

In France, engineers had long been deemed as social planners. Engineers bear a social responsibility of bringing rational order to the society through sound mathematical principles and hence they enjoyed elite status in society. As it was written in Downey et al. (2015):

> "For French engineers, demonstrating the ability, commitment, and discipline to become proficient in the mathematical foundations of engineering is to demonstrate that one has the moral character and reliability to warrant the trust of the Republic." (Downey et al., 2015, p. 90)

The earliest industrialized country in Asia, Japan, had established its own identity of engineers in society that combined the Western concept of individualism and the traditional Eastern minds of organizational attachment. As it was written in Downey et al. (2015):

> "To understand the distinctive features of engineering ethics in Japan, it is important to appreciate the role of harmony plays for Japanese engineers in both domestic and international professional relations." (Downey et al., 2015, p. 85)

The role of harmony mentioned in this quotation referred to the relationship between individuals and organizations. And in the Japanese culture, harmony can be achieved by hard-work which often indicates a sacrifice of individual ambitions. This notion of hard-work[8], from my view, might be understood more easily by its Asian neighbors.

For China, I would consider that due to the fact that modern science and technology are largely considered as learnings from the West that transplanted in the Chinese soil, Chinese engineers might have learned something more than just pure knowledge from where science and technology originated. Traces of all these concerns about engineers' social status in relation to self-development appeared in the Chinese engineering community. In addition to that, I tend to think that it is not the state-of-the-art of the current Chinese engineers' identity that has some national characteristics but its process of transformation differentiates the development of science and technology in China to other nations.[9] It is also believed that through an interpretation of the historical transformations, contemporary Chinese engineering practices and perhaps its future orientations can be better understood.

1.1.7. WHAT IS THE RELATIONSHIP BETWEEN CULTURE AND ENGINEERING?

> "The state of culture is a state of interaction of many factors, the chief of which are law and politics, industry and commerce, science and technology, the arts of expression and communication, and of morals, or the values men prize and the ways in which they evaluate them; and finally, though indirectly, the system of general ideas used by men to justify and to criticize the fundamental conditions under which they live, their social philosophy." (Dewey, 1939, p.23)

According to Dewey, culture is a set of relations. Since science and technology is a part of the culture, it seems to be quite obvious that culture would have a strong influence on engineering. It also seems to me that Dewey's definition of culture is quite elastic in the sense that it did not distinguish whether science and technology

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[8] In Japanese society generally, hardship is considered one pathway to mature selfhood. Edurance and perseverance are among the most frequently cited virtues in Japanese Society. (Downey et al. 2015 p. 85)

[9] Specified in detail in the later chapters.

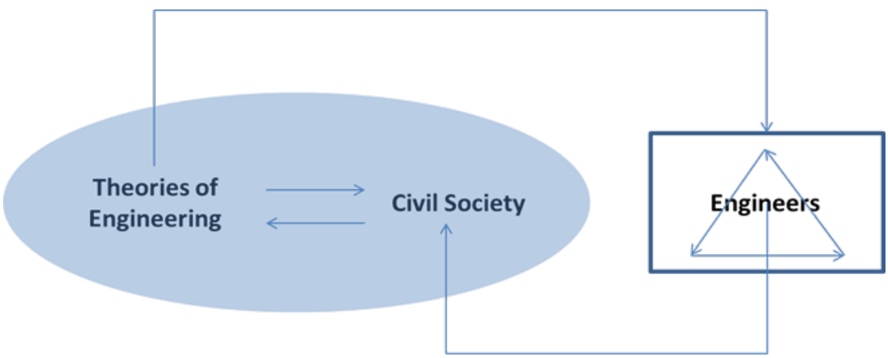
is treated as knowledge or as a social institution. Similar to that, laws, politics, industry, and commerce shared the same feature in his definition. Are they just human activities or social institutions as well? Taking into Latour's theory – the hybridization of the natural and social – into consideration, I tend to think that it does not matter. Because considering all of them as culture domains does not necessarily require a presumption that each of them was constituted within a boundary. Perhaps, Latour's contribution to the theory of science and technology is to dismantle these boundaries. In this respect, it is conceptually possible to discuss the relationships among engineering and these cultural domains without a clear definition of the boundaries. That is to say, in this thesis, I see engineering as an element of the culture, and so do I see other elements mentioned by Dewey.

Therefore, a study of the interrelationship among engineering and the other cultural elements can be characterized as a study of the relationship of culture and engineering. In fact, this relationship refers to the dynamics of engineering and its relevant elements in culture.

Based on my discussions in the previous sections, and to make my representation of the relations among engineering and the other elements concise, I perform some groupings of Dewey's cultural domains. I grouped those relatively philosophy concentrated elements as theories of engineering which is closely related to the scientific meanings of engineering in this thesis. I grouped those social movement like activities loaded elements into the civil society to pin-point the site on which the human meaning of engineering takes place. I draw a black-box which represents the commercial meaning of engineering because this meaning of engineering is manifested in commercial organizations. I put engineers inside the black-box because these organizations are normally the employers of these individuals.

Hereunder the diagram presents the theoretical framework of my thesis:

Figure1-1 Theoretical framework



In this diagram we see the theories of engineering – especially the scientific and the commercial schools – direct engineering practices by creating different types of engineering design methodologies. When these theories are assimilated by the company, they will be turned into more practical procedures of which engineers inside the company will follow. Considering that the process of engineering design is iterative, from a retrospective, it can be expressed in a circular shape, as the circulate triangle in the middle of the black-box.

The human meaning of engineering indicates that engineers shall be members of the civil society and in the environmental movements for example, we see numerous practices in this cultural domain that expressed this relationship.

We can also see a strong inter-relationship between theories of engineering and the civil society. On one hand, by modeling the civil society to the customers of technology, some strong evidence appeared in the sense that the innovation design methodology try to combine this cultural domain into its field of study. On the other hand, considering social movements as means of collective knowledge making the influence of the civil society to the theories of engineering can be traced. Perhaps, the best examples of these contributions to the theory of science and technology can be read in Jamison's publications such as Social Movements - A Cognitive Approach (1991), The Making of Green Knowledge - Environmental Politics and Cultural Transformation (2001) and most recently The Making of Green Engineers – Sustainable Development and the Hybrid Imagination (2013).

With this presentation of the relationships between engineering and its medium, it seems that a circle has been shaped which suggests that engineers are both influenced by and influencing the culture. However, this perception is largely based on my understandings of the Western experiences. The question is whether this understanding can fit into the Chinese context and be useful to help Chinese engineers to find their own ways of becoming good engineers. To some extent, this diagram becomes the hypothesis of my research, and my PhD study devotes to the testing of this "guess".

1.1.8. A TRANSLATION OF THEORIES TO PRACTICAL ISSUES

In order to bridge theories and practices, I make a simple chart to list the practical issues related to the theoretical questions presented above. Perhaps the careful readers of this thesis will find that they are not simply to reiterate the same question into other expressions. The aim of making this list is that from my interviews and observations, I found that my colleagues did think about all these theoretical questions but they expressed them in their own ways. For example, many of my colleagues think that scientific knowledge together with social skills will make a good engineer but is the term "social skills" precise in theoretical terms? And what is the content of "social skills"? As such I realized a gap between the language of theorizing and the language used in real life engineering. On top of that the interviews were performed in Chinese, and the problem of translation exists. In order to express the thoughts and ideas of my colleagues in their most original sense, I made my transcripts of interviews, as simple and straightforward as possible.

Here in this section the transcription of the theoretical questions to the everyday language in my best effort gave some examples of how my colleagues think about equivalent concepts and ideas.

The second intention of making a chart like this is to present to the readers in advance of the themes discussed in the interviews.

Table 1-1 Theoretical questions and practical issues

Theoretical Questions	**Practical Issues**
What distinguishes engineers from technicians?	What is the most valuable practice of an engineer?
What are the relationships between engineering and science?	Is more knowledge enough to become a better engineer?
What are the different meanings of engineering?	What are capacity buildings for?
What are engineering designs and their processes?	How to evaluate and management engineering designs?
Why did engineering become a "weak profession"?	Difficulties and confusions of becoming good engineers.
What are the national characteristics of engineering?	What are the Chinese characteristics of engineering?
What is the relationship between culture and engineering?	A hint of becoming good engineers.

1.2. METHODS OF STUDYING ENGINEERS

Since changes and personal experiences have become the main theme this PhD study, it indicated that this type of study shall be categorized as a socio-historical study of the engineering activities inside a company. After the narrative turn of sociology which started from the 1970s, the utilization of personal experiences – in terms of stories – has given birth to a series of research methodologies in the realm of sociology and historical inquiries. (Polletta et. al, 2011; Calhoun, 1998; Gotham and Staples, 1996; Maines, 1993; and Borisenhova, 2009). In these studies, the narrative turn of the sociology led to two major developments of sociology. In the epistemological sense, on one hand, sociologists learned from historians that general theories might be too abstract to certain social changes in a specific cultural context. (Calhoun, 1998) On the other hand, historical evidence might supplement sociological theories which derived from observations and logical reasoning of causes and effects, with a historical explanation of the causality and its consequences. In this regard, the validity of theories can be justified by significant specific historical events. (Maines, 1993)

In fact, both of these two orientations in the socio-historical studies of social phenomena after the 1990s tried to combine the essences of the sociological study – meaning generation – and the historical analysis – specific cause and effects narratives – together. (Calhoun, 1998) The foundation of this type of study was constructed on personal storytelling which sociologists used as empirical data while historians used as testimonies of events. However, in terms of socio-historical studies, storytelling might have a different meaning. According to Polletta et al. (2011) storytelling in a real life situation has the following features. First a story is an account of a sequence of events in the order in which they occur to make a point. Second, stories contain plots in which the cause and effect relationships are interpreted by the storyteller. Third, although the audiences expect cause and effect relationships to be presented in the stories, they did not expect the interpretation of the ending of a story be restricted to the sole version of the storyteller, in the sense that the audiences always want to provide their own interpretations of the story.

My approach is inspired both by Maines' (1993) perception of sociology and Bucciarelli's (1996) empirical study of engineering design via an anthropological method. Maines depicted sociology as a form of communication because sociologists cannot generate meaning solely from their own imaginations. It is through an understanding of the context, the languages of the storyteller that the researcher might express the meaning of stories without a misinterpretation of the authentic narratives. Also according to Maines (1993), sociologists can also be considered as narrators, in the sense that the researcher's own establishment of the interpretations of stories is quite necessary as long as he or she knows such reconstruct of the story contribute to what kind of inquiries they are attempting to answer, be it a general theory, or a historically specific theory, or even simply just a narrative explanation (Calhoun, 1998). Maines' perception of sociological narratives as a result of communication largely derived from his perception that all social phenomena are forms of communications. Perhaps what Maines indicated was that the entire research process in the name of a socio-historical study can be performed as a communication as well.

To my understanding Bucciarelli's research (1996) on the designing engineers in some American engineering firms is an established research which can be categorized as a socio-historical study on engineering design. To a large extent, Bucciarelli's notion of the "object world" mimicked the real life communications of engineering design work inside a company, and such a notion derived from his communications with the individuals involved. His interpretations of the design procedures and the organization of engineering designs were largely done in a way which treated engineering design as a communication process out of which a consensus instead of a decision was finally reached.

Bucciarelli performed a participant observation research in the companies as an external consultant. This gave him an opportunity to keep a moderate distance from the object of observation. In this respect, his book Designing Engineers can be considered as his reconstruction of the stories of what had happened in those companies with his involvement and observation.

Bucciarelli's application of the participant observation methodology to the study of engineering design was quite convincing and thus influenced not only this study but also some recent academic studies about the same topic in Europe[10] because it offered an approachable method to tackle the changes of engineering design inside a design organization. However, there are some differences between this PhD study and his research. First, Bucciarelli's research was performed in three different entities while this PhD study was performed in only one company but in order to balance an overly CGN centric view, an external interviewee from AREVA NP was invited. Second, as a mechanic engineer himself, Bucciarelli was quite familiar with the technical terminologies of mechanical engineering which happened to be the object of design he witnessed during his observation, while I was educated to be a chemical engineer who investigated a nuclear power plant's engineering design. According to Bucciarelli's notion of the "object world", I had a disciplinary divide to cross. I needed to learn their languages so that I can get some understanding of what they meant. For that purpose, I even needed to establish working relationships with them so that my communications with them could be done effectively, and that would finally lead to a willingness of their participation in my project. Otherwise, due to disciplinary barriers, my communication with them might be far too superficial. Thirdly, the fundamental differences between this PhD study and Bucciarelli's is that Bucciarelli's book can be characterized as a theory oriented sociological study, while my research is primarily narrative driven. For instance, the engineering design organization structure in CGN, from the outset, can be seen as

[10] F. Baird, C.J. Moore and A.P. Jagodzinski,(2000), An ethnographic study of engineering design teams at Rolls-Royce Aerospace, Design Studies 21 (2000) 333–355, Elsevier Science Ltd; Peter Lloyd, (2000), Storytelling and the development of discourse in the engineering design process, Design Studies 21 (2000) 357–373, Elsevier Science Ltd.

derived from disciplinary divisions but connecting this phenomenon to the traditions of Chinese engineering culture, such a structure might have another origin – the close relationship of engineering to politics. This discrepancy led me to connect engineering design – this social phenomenon – to its cultural roots.

The participant observation method was largely used as a supplement to the individual interviews performed in this study because it provided me with an access to the interviewees and also helped me to develop a relatively more precise interpretation of my research findings. This was the reason why such participatory observation was performed earlier than the interviews in this PhD study. Even though I claimed that theory generation is not the intention of this PhD study, I still did not abandon a cause and effect reasoning in my interpretation because that would be the logical foundation of my interpretation of the relationships which I indicated in this thesis.

Perhaps, what differentiates this thesis most from a theory generation work is the feature that I tried not only to provide a cultural reason for CGN's engineering design changes but also to illustrate how CGN engineers attempted to change the culture tacitly. This style may confuse the conventional relations of causes and effects but I was convinced by the stories given by my interviewees and a reading of an autobiography of a previous CGN engineer, that such two-directional reversible relationships seemed quite evident. In this regard, the cultural interpretation of improving engineering design in this thesis is not culture determinism in the sense that culture shaped engineering activities. It implies that culture can also be altered or at least influenced by individual designers' conscious actions, albeit, the effects might not able to be measured. Connecting personal engineering experiences and the culture, from a historical perspective, also indicates the situated feature or cultural sensitivity of this human knowledge making activity which I try to elaborate in this thesis. These narratives which derived from this dual directional relationship of engineering and culture and the socio-historical study of it depict the "reality" that I observed, was involved in, and reconstructed during the course of this PhD research.

1.3. RESEARCH PROCESS OF THIS PHD PROJECT

This research project had two phases, with the preliminary phase, and the later refined researches. In the preliminary phase, after some not very successful surveys about engineering design capacity, I carried out some preliminary interviews to CGN's top managers. At that time, since the higher ranked employees in CGN were normally more experienced, I was thinking that I might be able to get abundant information from such interviews. But I was wrong. Our company leaders normally think that they represent CGN – the company – to some extent. Therefore, in the interviews, I found they intentionally avoided expressing their personal opinions. This meant that their opinions were highly concentrated to the economic storyline of company development. The general manager of Taishan project considered the most effective way of improving CGN's engineering design as to upgrade our knowledge and expertise through project experiences, in the sense that as long as the project could be accomplished CGN's engineering design can be improved because the EPR technology – Gen 3 technology – is considered as more advanced technology. The deputy general manager of CNPDC – CNPEC's design division – rejected my request of a personal interview but replied to me in email saying that the capacity of engineering design was manifested by the qualification certificates issued by China's construction administration authorities, in the sense that as long as CNPDC was granted a certificate of performing nuclear power plant design then CNPDC's design could be regarded as completely legitimate which indicated that CNPDC was fully capable of ensuring the intrinsic safety of the nuclear power plant it designed.

Later, I was not sure to what extent the company leaders confused the concept of a physical person to a legal person, but it gave me a feeling that they were the company at the time when I communicated with them. Relying on such sources of information, this study could only be a study about the company as an economic legal person. Therefore, it would not meet my research ambition. It was after these fruitless attempts, I targeted my research at the individual engineers.

In order to collect personal stories, I needed to carry out my research by interviews. Due to the unsuccessful feeling of interviewing company leaders, I was not sure whether interviewing normal engineers would meet the same situation. With this concern I adopted a participant observation as a supplement. My position in CNPEC as the technology transfer project manager for the Taishan EPR Project largely supported the adoption of this research methodology.

It took a long time for me to carry out the interviews in the second phase of my research not because the recording and transcription of interviews was time consuming but because I had to find appropriate people to be interviewed. As a requirement of the oral history interviews, interviewees had to grant the interviewer a right to publish or release their words. In this respect, their words serve as a verbal testimony of what has happened to them or what they have witnessed. (OHA, 2009) This requirement, as I understood, ensures the liability of this type of research in the sense that the interviewees agreed to the interviewer that their words were not fabricated on the demands of the interviewer. The biggest problem for me, due to my failure in the preliminary interviews, was who were the people who could provide me such a guarantee and grant me a right to publish part of their personal lives, and offer opinions which might deviate from or be critical to the dominant company policies and perceptions.

I tackled this problem by initiating a company sponsored research project to work together with our engineers in the name of knowledge management with an intention of improving engineering design. Through this project, we learned the limitations of a social science method, and importantly we realized how far the result of this seemingly impartial, omnipotent theory generation methodology could deviate to our common initial intentions. Through this experience we all learned that improving engineering design might have other meanings than just a CGN version of interpreting the validity and adaptability of scientific management. It might be true that knowledge is socially made inside CGN, but it might be more important to understand how the social and cultural dynamics inside and outside this company that lead to the making of knowledge and our perceptions of our work.

This period of working together with our design engineers, and design related engineers gave me an opportunity of interviewing all of the members of our research team. Through the interviews and casual talks, their participation in the making of a “new” culture related to improving engineering practices in China gradually became traceable for me.

1.4. STRUCTURE OF THIS THESIS

The PhD thesis consists of four parts, with the first part – Introduction and Chapter 1– serving as the problem formulation and theoretical discussions of the research questions. The second part – Chapters 2 and 3 – consists of a literature study about the engineering culture in China and nuclear power engineering practices in China specifically reflected by CGN’s engineering projects. The third part – Chapters 4 and 5 – are primarily empirical “storytelling” focusing on how the broad culture influences CGN engineers’ practices and their thoughts and attempts at making changes in their own practices. Chapter 6 is the conclusion of this thesis where some theoretical and practical implications of the research findings are presented.

A general picture of the engineering culture related to nuclear power technology is sketched from a Chinese perspective in Chapter 2. In this Chapter, I ascribe the lack of a social movement against nuclear power in China to the dominant utilitarian perception of science and technology established over China’s history of modernization. This indicates that the research performed in this PhD project required a transcendence of this cultural barrier.

In Chapter 3, I tried to connect CGN’s path to engineering design with nuclear power technology’s rise and fall in contemporary China. Also, I tried to demonstrate how Chinese traditional habits of engineering were manifested in this modern company. As such, I want to show how culture influenced CGN’s engineering practices, especially how the powerful economic thinking triumphed in the shaping of CGN engineers’ perceptions toward their own work. A lot of the topics discussed in this chapter originated from my casual talks with various anonymous CGN engineers, however, since most of the information mentioned was documented by published books and articles, I wrote this chapter mainly in the style of a documentary history.

In Chapter 4, I present a story of CGN engineers' attempt of challenging the dominant culture of engineering. My involvement in this attempt was quite evident; therefore, by and large it is an illustration of the preliminary researches of this PhD project.

In Chapter 5, CGN design engineers' experiences are presented in an oral history approach. The organization of this chapter is not arranged topic by topic but person by person so that a complete story of the interviewee is presented without interruptions. The titles of engineers in terms of system design engineers, equipment design engineers, and commercial engineers are not intended to categorize them into sub-classes and hence to place them into smaller social groups as the social construction of technology studies. The intention of giving them those titles is rather to relate their experiences to their real life work in CGN, which might help the reader to understand their particular personal history.

Chapter 6 is a conclusion and reflection chapter. The aim of this chapter is to make engineers' attempts of changing culture more visible and understandable.

CHAPTER 2. HISTORICAL AND CULTURAL BACKGROUNDS

2.1. CULTURAL IMAGES OF SCIENCE AND TECHNOLOGY IN CHINA

The cultural images of science and technology in this thesis refer to a broader social and perhaps philosophical perception of science and technology in China. Since it is a combination of a wide range of topics which include science and technology education, the sociology of science and technology, some traditional philosophy relevant to science and technology, and the contemporary Chinese politics of science and technology it might be appropriate to generalize these elements about science technology and society in China as cultural elements, and as such the context of science and technology development in China might be revealed. In plain words, in this thesis, I attempt to carry out a study on the relationship between Chinese culture and science and technology. Like many scholars who entered into this field, my point of departure started from the learnings of Joseph Needham.

Needham – an English biochemist at the Cambridge University – studied Chinese in his late thirties and was the first to reveal to the English-speaking West the richness and complexities of the Chinese scientific traditions. Therefore, later students of the history of Chinese science and technology start from his argument which was in fact based on a presumption that Chinese science and technology development should have certain Chinese characteristics to study the history of Chinese science and technology. (Akcetin, 2014) Needham implied that due to the differences of cultures, science and technology development might deviates into different modes, in the sense that China might develop its own style of science and technology. As Needham (1979) put it:

> "Why, then, did modern science, as opposed to ancient and medieval science (with all that modern science implied in terms of political dominance), develop only in the Western world? Nothing but a careful analysis, a veritable titration, of the cultures of East and West will eventually answer this question. Doubtless many factors of an intellectual and philosophical character played their part, but there were certainly also important social and economic causes which demand investigation." (Needham, 1979, p. II)

A seemingly logical flaw of Needham's argument was discovered by contemporary scholars like Graeme Lang in Hong Kong. Lang in his articles published in 1997 questioned Needham's presumption by postulating a counter question to

Needham's big question: why should culture be different? However, from my perspective, it is an even more inapproachable question. Therefore I would just admit the differences of cultures as taken for granted.

Lang's (1997) perception of the Chinese characteristics of science and technology development, especially science, rested on the more physical aspects of Chinese culture, specifically, its geopolitical feature. In Lang's perspective, China – a geographically unified empire state – was not supportive to the emergence of independent universities in the middle ages; however, a separated Europe was optimal for academic freedom.

My understanding of Lang's theory is that he tried to provide some physical evidences of Needham's argument which seemed to be entirely constructed on philosophical reasoning. In fact, Lang did support Needham's identification of the fundamental cultural difference between China and the West that influences science and technology develop in China, as Needham (1979) put it:

> "In the first place it can be shown in great detail that the philosophia perennis of China was an organic materialism. This can be illustrated from the pronouncements of philosophers and scientific thinkers of every epoch. The mechanical view of the world simply did not develop in Chinese thought, and the organicist view in which every phenomenon was connected with every other according to hierarchical order was universal among Chinese thinkers." (Needham, 1979, p. 21)

This fundamental difference led to a strange phenomenon in China, which might still be the case today, that even though Chinese people achieved many successes in the making of knowledge about the material world and applied it to human lives, it seemed that such knowledge was not theorized as it was in the West. In other words, science and technology was perhaps not theoretical but rather practical knowledge in China. Needham (1979) put it explicitly as:

> "I should not want to disagree altogether with the idea that the Chinese were a fundamentally practical people, inclined to distrust all theories." (Needham, 1979, p. 23)

In this respect, pre-modern China was culturally incapable of producing science, in the sense that China's traditional irrational theory was different from the European mechanical physical science. Underneath these discussions of pre-modern Chinese science and technology development, a cultural determinism was quite evident. However, provided that the above arguments made sense in constructing a relationship between culture and science and technology in China, their basic presumption of a fixed culture was worth questioning. Culture is in fact flexible and changes over time (Dewey, 1939), which might indicate differences of its influences on science and technology in China through a historical retrospective. As far as I am concerned, I am not constructing my argument on culture determinism. My argument is constructed on the following presumptions.

First, the focus of this thesis is modern science and technology in China, instead of pre-modern knowledge which might be termed as "science" in some modern sense. That is to say, I perceive modern science and technology a pure Western invention which is almost the same throughout the world. However, it is not to say that Chinese traditional knowledge has no impact. My argument is that the impact of pre-modern Chinese knowledge rested on the adoption of modern science and technology in China rather than the creation of science and technology with "Chinese characteristics". What made China different from the West are perhaps its cultural perceptions of such Western inventions – both knowledge and its institution. It is due to a different cultural perception of science and technology that science and technology were adopted differently in China. Relating these concerns to nuclear power science and technology, they might be able to explain why the promoter's culture prevails over the resister's culture in contemporary China.

Second, taking culture as a flexible and changing factor does not mean that I deny its influence. It means that Chinese traditions and Western concepts might have different influences in Chinese adoptions of science and technology in different periods of time. It is implied that in each period of Chinese history, there existed different culture motifs relevant to science and technology development. Culture evolves as well as the adoption of science and technology changes. With this presumption in mind, I might be able to discuss how the dynamic of the promoter's and the resister's cultures of nuclear power is going to evolve in the future.

These presumptions of the relationship between culture and modern science and technology in China derived largely from my understandings of the historical changes of the politics or sociology of science and technology, and science and technology education in China.

When China started its modernization in the late 19th century, the modes of knowledge production began to differentiate in this ancient civilization. Chinese Learning (Zhong Xue) and Western Studies (Xi Xue) gradually defined their own paradigms. The modernists – the promoters of Western Studies – believed in the superiority of Western science and technology and argued that their appropriation in China would enable the nation to reach the economic and industrial level of the West. On the contrary, the conservatives insisted a moral and spiritual superiority in Chinese Learning and rejected Western Studies which were regarded as a threat of the deterioration of Chinese civilization. (Elman, 2005) In this period, the modernist intellectuals struggled on two fronts. On one hand, they were confronting the Western rational scientific and technological powers with an indigenous barren legacy which relied on irrational cosmology and experiences. On the other hand, they struggled to get rid of the shackles of the conservative knowledge making paradigm in which social norms were seen as prestigious knowledge while knowledge about natural and physical things was deemed as inferior. In this milieu the only choice left to the modernists was to learn from the West. (Kang, 2012)

Underneath the bifurcated attitudes toward Western science and technology, was a common point of departure from which the conservatives maintained their hubris while the modernists adopted an air of humility. The point of departure was that both of them considered the Chinese defeat in the Opium War in 1840 between China and Britain only as a defeat by force instead of a loss of civilization and civilized values.

Needham mentioned in his five-volume Science and Civilization in China some Chinese contributions to the Western development of modern science and technology, such as gunpowder and the compass. (Needham, 1986) These Chinese ancient inventions, in the conservatives' eyes, were nurtured by Chinese knowledge. It was the Westerners' abuse of these Chinese inventions that finally defeated the Chinese army. In this respect, it seemed that the Chinese were defeated by their own feats, and also proved that the Chinese were morally and intellectually superior. (Ku, 1915) The modernists were more realistic, for, to some extent, they sensed the great power behind the gunboats and cannons which could not be manufactured in China. It was the method of manipulating the non-human world with rational systematic thinking. However, looking back into the Chinese legacies, the modernists found nothing equivalent to mobilize.

Even the natural philosopher – from the Chinese standpoint – Song Yingxing (1587-1666) who wrote the book Tian Gong Kai Wu (Chinese Technology in the Seventeenth Century) in which the production processes of a large array of commercial goods such as paper and wine were elaborated in detail similar to contemporary chemical processes, was a follower of Confucius. Song appeared to develop his approach to knowledge based on observation and experiment. However, unlike the European scholars who used their observed facts to mirror the process of nature, Song sought to unveil the rationale behind the cosmos as a medium to achieve social and political order. (Lee, 2009) In the sense that he made an analogy of nature to humanity, while the separation of human and nature was evident in Western studies in Song's age. His mixed perception of nature and humanity can be reflected by the expression he used to describe recycled paper. In Tian Gong Kai Wu recycled paper was termed as "reincarnated" paper, meaning literally the "returning of the soul". (Song, 1933)

In this regard, the modernists ascribed the backwardness of Chinese industrial and military power to the lack of modern science and technology. However, at the period, early modern period of China, the foundation of Chinese culture was not shaken as it was in the 20th century. Neo-Confucianism which integrated more traditional Confucianism with Taoism and Chinese Buddhism remained dominant. (Kang, 2012) Therefore, the core culture of China in the late 19th century related to knowledge making, was still focused on human relations and social order. Such a focus, according to Needham and others impeded the development of modern science and technology in pre-modern China. From my perspective, this dominant Confucian culture in the late 19th century, reflected the specific attitude toward Western science and technology in China at the time, and its legacy still casts its influence on contemporary Chinese perceptions of science and technology. This specific culture perception is what might be called a utilitarian view of science and technology. The ideology "learning from the advanced technologies in the West to strengthen China" became the motif of Chinese politics of science and technology development, and it took root in the late 19th century.

The establishment of the Republic of China in 1911 and the later May Fourth Movement in 1919 overthrew the dominant Confucian culture in China. Science and Democracy appeared to be the major weapons used to attack China's traditional feudal culture in the May Fourth Movement. In this period, it is hard to conclude that a pro-science and technology culture had been established in China, but its traditional values were subjected to fierce criticism and anti-traditionalism became the dominant trend. (Kang, 2012) Early 20th century was an era of political turmoil manifested by constant civil wars in Chinese history. It was in this period, traditional Chinese culture was reviewed by Western educated Chinese intellectuals by Western approaches with a hope to find a solution for the Chinese problems at that time. Among them Dr. Hu Shih (1891-1962), a student of John Dewy, was perhaps the most influential. As the president of Peking University – China's first modernized University – he led the May Fourth Movement, which could be regarded as one part of China's New Culture Movement. (Grieder, 1970) In his book The Chinese Renaissance published in 1934, Hu Shih argued his perceptions of China's problem:

> "The problem of China, however multifarious and complicated it may seem at first sight, is in reality one of cultural conflict and readjustment. It is the problem of how to bring about a satisfactory adjustment in a situation where an ancient civilization has been forced against its own will into daily and intimate contact with the new civilization of the West; where the old civilization has clearly proved itself hopelessly inadequate in solving the pressing problems of national existence, economic pressure, social and political disorder, and intellectual confusion; and where, for reasons hitherto never fully understood, the new invading civilization has not yet succeeded in either grafting itself upon the traditional culture or being extensively adopted in working out a new cultural equilibrium on a national scale." (Hu, 1934, p.1)

In contrast to the modernists in the 19th century China, this new generation of Western educated intellectuals ascribed social disorders and various problems of China to the inadequacy of Chinese ancient civilization. Furthermore, Hu Shih pointed out his proposed solutions to "the problem of China" as he made a comment on the Chinese 19th century modernist Wang Tao's words:

> "But Wang Tao was essentially right in prophesying that it was the new tools of the West that would unify the ways of life of the nations of the world. For all the social changes in China can be traced to their early beginnings in the days when the new tools or vehicles of commerce and locomotion first brought the Chinese people into unavoidable contact with the strange ways and novel goods of the Western peoples." (Hu, 1934, p.94)

According to Hu Shih, Western science and technology supported by its social institutions was the solution to reunite China in the 1920s. Therefore, what he called for was a wholesale adoption of Western science and technology in China's soil. However, what also differentiated Hu Shih from his later socialist counterparts and his opponents was that Hu Shih proposed a gradual pragmatic evolutionary change of Chinese culture instead of a prompt revolution. As Hu Shih (1934) put it:

> "In some cases it has been necessary to undermine and destroy the old obstacles and vested interests in order to accomplish a change; in such cases, the conscious movement amounts to a revolution and often requires long periods of persuasion and propaganda. In other cases old ideas and institutions are rejuvenated by suggestive influences from the West, and reforms are brought about peacefully and without serious break with the past. In still other cases long association with the new culture has made certain new ideas and practices so self-evident and so natural that they are quietly adopted and old institutions are modified or replaced without much ado……In such diffused changes of culture two factors are necessary: contact and understanding." (Hu, 1934, p.27)

Learning from the West, in Hu Shih's interpretation was a cultural transition equivalent to the persuasion and education of Western science and technology and democracy to Chinese people. Therefore, he hoped that a breakthrough of changing Chinese culture could be started in the reform of Chinese language. Thus, his main contribution in the May Fourth Movement could also be reflected by his contributions to the advocacy of using vernacular Chinese, in Chinese literature and education. (Grieder, 1970)

However, unlike Hu Shih who thought Western science and technology as a resolution of China's problems, his opponent Ku Hungming (1857-1928) – a professor in Peking University – claimed that Chinese moral values were indeed the answer to the Western turmoil which was experienced in the First World War. Ku was a paradoxical figure in Chinese history. He was born in Malaysia as a son of Chinese and British immigrants. He received his higher education in Edinburgh and Leipzig. After his graduation, he served as a diplomat in the government of the Qing Dynasty. When the last Emperor in the Chinese history Xuan Tong resigned his crown in 1911, Ku chose to leave the government and accepted a teaching position in Peking University. In all Ku's life, he contended that Chinese traditional values and culture needed to be respected by the West. His publications and translations of Chinese canons, focused on the propagation of Chinese traditional culture to the West. Among his voluminous books, The Spirit of the Chinese People published in 1915, was perhaps the most influential, in which Ku insisted on the superiority of the Confucian learning about social order and the spiritual characteristics of Chinese people. (Kong, 2010) According to Ku, the focus on strength – specifically machines and technology – in the Western culture was the origin of chaos in the First World War in Europe, on the contrary Chinese culture emphasized harmony which would bring ultimate peace to the world. (Ku, 1915)

In the early 20th century, Hu Shih's idea was supported by early Chinese socialists such as Chen Duxiu. (Grieder, 1970) In the cultural milieu which deemed Western science technology and democracy as forces of advancement, Ku's conservative ideas were rather weak in terms of influence especially among the young students in the modernized universities such as Peking University. (Hu, 1934; Grieder, 1970) But still we cannot deny that there existed a long lasting intellectual debate about science and technology and their adoption in China. That might be the reason why Hu Shih perceived a conflict between Western civilization and Chinese traditions, and hence proposed a gradual evolutionary change of China's new culture.

However, this type of gradual change toward pro science and technology culture was interrupted by the later Japanese invasion, and the subsequent civil war between the socialists and the nationalists struggling for political power to reshape China. (Kang, 2012) As far as I am concerned, a pro science and technology culture was established in the new socialist China – People's Republic of China – after 1949, especially in the 1980s and onward. This pro science and technology culture can be reflected in three aspects, the political aspect, the educational aspect and the sociology of science and technology in China.

Marxism emphasized science and technology's roles in the shaping of societal relations and social order. (Hong, 2008) When Marx's philosophy of science and technology as the momentum of social development and enhancement of human life, turned into be the ruling political ideology in China, science and technology development has consequently been strongly promoted by each generation of Chinese political leaders since 1949. In Mao's years, "science for the people" had been the main theme of Chinese science and technology policy. (Wisnioski, 2010) However, under this seemingly liberalized slogan, science and technology development in China was heavily influenced by class struggle ideology which in fact addressed central control. (Paltemaa and Vuori 2009) In Mao's perceptions, the power of science and technology, in his term productive forces, should be controlled by the proletariat which had become the ruling class, therefore, scientists and engineers were required to be both properly ideologically minded and professionally competent. Social or political movements became Mao's major instruments of policy implementations. In the Great Leap Forward (1958-1961) and the Cultural Revolution (1966-1976) the autonomy of scientists and engineers was subverted. (Zhu, 2010) Scientists and engineers were classified as bourgeois, and many of them were sent to the countryside to learn from the peasants. Just working hard became the dominant belief of success, and scientists and engineers were transformed into hard working workers. In general, in Mao's era science and technology development in China experienced stagnation, for instance, during the Great Leap Forward in order to meet steel production quota, peasants melted down any scrap metal they could find in their homemade backyard furnaces. Only science and technology related to the military progressed, such as the atomic bomb. During the Cultural Revolution 106 out of 434 colleges of higher education was simply closed down and the enrollment in the remaining colleges was severely reduced. (Zhu, 2010)

Not only were scientists and engineers demoted to an inferior social position in Mao's years, social studies about science and technology in China were also suppressed. Intellectual discussions about the social or ethical aspects of science and technology were eliminated in the name of ideological purity due to a concern that, in general, sociology was seen as "bourgeois" or capitalist academic remnants which needed to be wiped out in socialist China. (Su, 2003)

After the death of Chairman Mao, his Cultural Revolution which from the outset could be seen as a mass social movement that included a cultural reflection of science and technology development in China was indeed a fierce contest between revolutionary and anti-revolutionary ideologies was abandoned. (Zhu, 2010, Kang, 2012) Putting Cultural Revolution into its contemporary global context, it seemed that it was a missed opportunity in China for a public rethinking of science and technology's roles in society. Compared to the student movement and environmental movement in the 1960s and 1970s in the United States and other Western Countries, Cultural Revolution seemed like a misguided social movement under a seemingly "good" name. In this respect, it might suggest, from an environmental activist point of view, why the ecological concerns about science and technological development emerged later in China than in the West.

Deng Xiaoping – the commonly recognized second generation leader in the history of People's Republic of China – deviated from Mao's perceptions of science and technology. In his policy of "reform and opening-up" a new round of learning from the West began. Science and technology were explicitly recognized as key contributors to economic development in accordance with Deng's policy of "four modernization" in which strengthening Chinese economic power persisted as its essence. In the 1990s and on into the 21st century, Deng's visions of science and technology development in China were inherited by his successors. President Jiang Zemin in his publications about science and technology insisted on their roles as "productive forces" in society; however, different from Mao's perceptions, science and technology in Jiang's perceptions shall be oriented to the booming of market economy. Therefore, innovations were seen to be critically important to modernizing Chinese society and scientists and engineers were treated as valuable intellectual resources by the state. (People's Daily, 2001-3-22) President Hu Jintao, standing on the shoulders of his predecessors proclaimed his policy which can be generalized as "scientific development" in which sustainable development and some elements of social justice relating to science and technology development were brought into consideration. (Xinhua News, 2006-1-9) This corresponded to some local governments' attempts of recalculating their Green GDPs after his speech. (Li and Lang, 2009) In recent years, President Xi Jinping, continued the science and technology development policy ever since Deng's years, meanwhile he pointed out some essential science and technologies of which China should give priority, such as the info and bio science and technology, and new energy technologies. (Xinhua News, 2014-6-3)

All these statements and modifications of China's science and technology policies in the post-Mao era indicated a closer connection of science and technology to market driven economy and to politics. Such intimate relationships were reflected in Chinese science and technology education. Regarding primary and secondary education, science and technology were taught as "privileged knowledge". (Liu, 2008) Liu Yongbing in Nanyang Technological University in Singapore analyzed Mainland China's primary schools' language text books and depicted a pro science and technology discourse in China's primary education. As Liu found, the logic of narratives about science and technology in the textbooks was constructed as follows. Firstly, modern science and technology are characterized as entities that contribute to the solution of human problems, and therefore, they offer a better life to the people. Secondly, since modern science and technology are accessible and beneficial to all the people and society, they are the "privileged knowledge" for children to learn. Finally, rational mind and scientific attitude are the very foundation for that learning to be enacted. (Liu, 2008)

This sort of one dimensional thinking which praised the benefits of science and technology while disregarded their negative social and environmental consequences limited young students' imaginations about other possible interpretations about science and technology that in reality might be true. As Liu (2008) put it:

> "In this discourse, modern science and technology are legitimized as modernity and rationality. Individual and social betterment are portrayed

> as the direct result of the development of science and technology in this rationality or pragmatic view. In this rationality, the knowledge of science and technology is held to be universally applicable and accessible, and yet this position excludes the possibility that the opposite may be true." (Liu, 2008, p. 318)

According to Liu, such intentional admiration of science and technology in education derived from a deeper cultural background which Liu described as the promotion of a "business as usual" mindset shared by the government and China's newly emerged cultural – specifically commercial – elites after 1978. (Liu, 2008)

China's focus in higher education can be traced by its scientific and technological research publications. A group of researchers (Kostoff, et al., 2005) in the United States published an article about the structure and infrastructure of Chinese higher education by tracing 25 years' Chinese academic output in SCI and SSCI (Science Citation Index/ Social Science Citation Index) articles. Their findings can be summarized as the following:

> "China's publication of SCI research articles has had an annual exponential growth rate of 20% over the last 25 years. The major themes of these articles have shifted gradually over time from multidisciplinary science, medicine, and life science in 1980 to materials, chemistry, and physics in 2005, in that order." (Kostoff, et al., 2005, p. 1571)

When comparing China to the United States the following differences can be unveiled:

> "The difference in thematic emphasis between the USA and China is dramatic! China emphasizes the physical and engineering sciences that underpin defense and commercial needs. The USA emphasizes research areas focused on medical, psychological, and social problems. There are even research areas where China leads the USA in absolute numbers of research articles published." (Kostoff, et al. 2005, p. 1573)

According to Kostoff and his colleagues, the growing numbers of China's SCI publication was due to more frequent international collaborations between Chinese scientists and Western colleagues such as the Americans and the Japanese after the 1980s. (Kostoff et al., 2005) This phenomenon reflected the reach of "reform and opening-up" policy to the science and technology research sectors in China. Furthermore, their findings posed other implications. Kostoff group's findings were consistent with Liu's in the sense that both of them indicated a pro science and technology education in China. In this respect, science and technology education in China can be interpreted as unbalanced. On one hand, researches with market values were given extensive focus and investment, while those studies without short-term returns such as social sciences, and sociology were largely marginalized on the other. Among these studies of liberal arts, philosophy and sociology, social studies about science and technology held its unique position in Chinese academic context.

In 1978 Deng Xiaoping encouraged some scientists and engineers – including China's prestigious physical scientist Qian Xuesen who made great contribution to China's military research in the 1960s and 1970s – to establish the Chinese Society for Dialectics of Nature (CSDN). The name of this academic organization derived from Friedrich Engels' publication Dialectics of Nature (1925). (CSDN Website1 Accessed November 20, 2014) The establishment of CSDN represented the rejuvenation of Chinese social studies about science and technology in the new socialist China. CSDN and its journal Dialectics of Nature since its beginning has become the leading academic forum devoted to the philosophy of science and technology. In this forum, Chinese scholars started to reflect the roles of science and technology to economic development and to consider some of science and technology's negative consequences to nature. (Zhu, 2010) Since CSDN's establishment, China's social studies of science and technology have been channeled to the realm of Marxist philosophy of science and technology. In the first national meeting of CSDN members held in 1981, one of the executive directors said in his opening speech that CSDN was setup to promote Marxism studies in China, therefore, members had to avoid a tendency to indoctrinate Marxism on one hand, and to prevent also a tendency to deny it on the other. Even though he also addressed international collaboration between Chinese sociology of science and technology studies and its Western counterpart, Marxism remained the dominant ideology which needed to be insisted upon. (CSDN Website2 Accessed November 20, 2014)

In CSDN's later national meetings which took place every five years, the language changes in the speeches were evident, in the sense that obvious ideological wording such as Marxism was replaced by the wordings propagated by Chinese political leaders. In its 2006 national meeting, speeches given by its newly elected executive directors were highly consistent with the concept of "scientific development" proposed by President Hu Jingtao. (CSDN Website3, Accessed November 20, 2014)

Membership to CSDN from its beginning has always been open to government officials, professors in philosophy departments in Chinese universities, and directors of social studies in Chinese technical universities etc. (CSDN Website2 and 3, Accessed November 20, 2014) Therefore, the mainstream of China's social studies about science and technology has long been surrounded over Marxism. However, Qin Zhu – a professor in Dalian University of Technology – identified several deviations of the ideological approach toward a more professional approach which focused on ethical, environmental, and social issues of science and technology, not only their productive functions, in Chinese social studies of science and technology. (Zhu, 2010) According to him, such limited deviations derived from the introduction of Western STS (Science Technology and Society) approaches to China. Noticeably, in the 1990s two scholars, Yin Dengxian from Chinese Academy of Social Sciences (CASS) and Li Bocong from Chinese Academy of Sciences (CAS) respectively, visited United States. After their return, due to the visits of two American STS scholars – Stephen H. Cutcliffe and Carl Mitcham – to CASS the Journal of Dialectics of Nature devoted a special issue (supplement no.1, 1992) to STS issues. In those universities such as Tsinghua University – China's leading technical university – where there are more opportunities of international collaborations on STS studies, professional approaches of social studies on science and technology began to be adopted. (Zhu, 2010)

Based on a CSDN's statistics, currently there are 20 doctoral programs based in the philosophy departments of Chinese universities leading to a PhD degree of STS studies – precisely a degree majored in the philosophy of science and technology with Dialectics of Nature disciplinary training – among all Chinese universities, and 70 programs leading to a Master's degree. (CSDN Website1, Accessed November 20, 2014) These schools and their faculties are the major sites and participants through which social studies and researches about science and technology in China are carried out. However, compared to the massive number of PhD and postgraduate programs in scientific and technological disciplines, such a two digits number seemed insignificant.

In addition to the indigenous studies of science and technology policy in China, contemporary Chinese science and technology policies received some international attention. Paltemaa and Vuori from the University of Turku, in Finland published an article discussing regime transitions in Chinese politics of technology in 2009. According to them Western discussions on whether society has a deterministic influence on technology or technology has a deterministic influence on society, were seemingly invalid in socialist China after 1949. What they observed is that the socialist China (PRC) since its establishment has based its policies of science and technology development on the assumption that its decisions can have major effects on society. (Paltemaa and Vuori, 2009) This is largely due to the intrinsic utilitarian perceptions of science and technology in Marxist philosophy of science and technology. (Hong, 2008) However, what differentiate Deng and his followers' policies of science and technology to Mao's was the criteria of the choice of technologies. In the sense that under Mao's reign technologies with "revolutionary utilitarian" value were chosen, while in Deng's "four modernization" regime, technologies with "pragmatic utilitarian" value was chosen. Mao aimed to prevent the concentration of technical control into the hands of a few experts, thus proposed his mass-science. Under this mode, Mao intended to liberate the workers from being merely the appendices of machines, and workers should be the developers of technology through their own experiences gained in production. In this respect, technology should not only be developed primarily by the experts in the laboratories. Hence, an elimination of social status differences was necessary. Consequently, such policies led to the adoption of alternative technologies in China in the 1960s and 1970s. Deng's "pragmatic utilitarian" implied that there should be less restrictions and limits to science and technology development, and proposed more tolerance to their impacts on society. A social hierarchy based on expertise should be tolerated, in reality strengthened, technological borrowing from the West became encouraged, and as such the masses' role in science and technology development was downplayed. (Paltemaa and Vuori, 2009)

Relating contemporary Chinese politics of science and technology to its historical context, I would conclude that the utilitarian perceptions on science and technology remained constant throughout China's history. In pre-modern China, knowledge about nature and instruments was regarded as inferior to the more superior knowledge about social orders. Even in the more liberal years of Chinese modernization, science and technology in the modernists' eyes was something useful to reshape Chinese civilization. Compared to the socialist regime which appreciated science and technology as paths to wealth, power and social control, the liberal scholars' evolutionary change proposal seemed moderate. Traditionally, Chinese people respect knowledge (Liu, 2008) however, it has been in China's modernization process science and technology has gradually taken the place of social understandings as "privileged knowledge". Therefore, contemporary Chinese scientists and engineers as experts received their higher social standings over those with less scientific knowledge. They are now equivalent to the cultural elites in pre-modern China. The establishment of this unbalanced pro science and technology culture has had a strong influence on public participation of environmental politics in China, and specifically to the development of nuclear power engineering.

2.2. CULTURAL REFLECTIONS OF SCIENCE AND TECHNOLOGY AND ENVIRONMENTAL ACTIVISM

Some academic studies about China's environmental regulations and the civil society reached to a conclusion that Chinese environmental politics is a one party led self-restricting power and sectorial interests' compromise, affiliated to economy growth. (Lang and Xu, 2013, Carter and Mol, 2006, Li and Lang, 2009, McLaren, 2011, Wu, 2013, Xie and Heijden, 2010, Zhang and Barr, 2013) In general political opportunities for the development of environmental activism in China seem quite limited. (Xie and Heijden, 2010, Roberts, 2007) On one hand, environmental activism in China has remained fragmented and highly localized focusing on specific governmental projects or regional pollution incidents (Wu, 2013), even though the situation of the authoritarian control over environmental protection seem to be lessening in recent years, the government is still in fear of losing control over society, on the other hand. (Roberts, 2007, Lang and Xu 2013, Wu, 2013)

Without a public space for expressing opinions about environmental pollution which might deviate from the mainstream economic development discourse, Chinese public participation in environmental issues seems weak and difficult to achieve. From my perspective, the instability of the Chinese public spaces of environmental activism derives from the following reasons. First, due to the dominant political milieu which favors central control, national scale environmental movements remain invisible in the public eye, while government supports the enhancement of environmental consciousness via a series of personal activities such as photo shooting of the natural landscape and wild animals. (Zhang and Barr, 2013) In this respect, the Chinese environmental activism lacked a spirit of critical reflections on human economic and industrial activities. In the sense that even though the aims of such activities can be understood as promoting environmental conservation habits or culture among Chinese citizens by rendering them the un-polluted or destroyed scenes of natural beauty, such approaches remain weak in resolving social tensions among different social groups which might be expressed as environmental issues, such as the controversies to some government led infrastructure projects. Second, due to the lack of critical reflections on economic development by boosting Chinese industrial power, especially to science and technology, some technologies which were deemed as environmentally dangerous in the West were treated as advanced environmental friendly technologies in China such as the waste incineration plants and nuclear power. As far as I am concerned, these silences in Chinese environmental debate seem to be the logical consequences of the pro science and technology culture in contemporary China, a culture that is strengthened by the political system of the Chinese society. This perception of Chinese environmental politics can be read from some research reports published by scholars in Hong Kong.

In the article anti-incinerator campaigns and the evolution of protest politics in China published in 2013, Lang and Xu studied three Chinese campaigns against incinerators, in three Chinese cities, namely Beijing, Guangzhou, and Wujiang. All of these campaigns were quite successful in that either the campaign led to the cancellation of the project or an indefinite postponement of the projects. Another common point of these three campaigns was manifested by their NIMBY feature, which identified a regional and limited focus of such environmental activism. (Lang and Xu, 2013)

In all these three halted projects – probably relocated – the local governments claimed that waste-to-energy incinerators were technologies which would reduce the burdens of the environment, meanwhile in order to justify their claims, scientific and technological evidence was provided, by ensuring that the technologies to be adopted in these projects met the highest EU standards. However, such one-sided guarantees were insufficient to lead to consent on the part of the local residents. (Lang and Xu, 2013)

In both the Beijing and Guangzhou cases, it seems that the failure of the projects derived from the governments' careless decisions on the choice of the plants' locations. In the case of Beijing, the intended incineration plant site was chosen in Liulitun, Haidian district where scientists, academics, from Chinese prominent universities such as Peking University and Tsinghua Universities lived together with newly established commercial elites from IT industries. In the case of Guangzhou, a number of middle class journalists lived in the nearby area. Protesters in these areas were accustomed to use their political and media connections in the expression of their unhappiness about waste incinerators. They possessed an advantage of making their voice heard by the government, and known by a broader scale of the public, thus led to the government's rethinking of their choice of location. Another important factor which led to the fierce objection to the projects was derived from China's privatization of housing. In both regions, the most ardent participants were middle-class residents who had bought recently-built condominium apartments in nearby districts. Under a fear that the construction of an incineration plant which might cause a depreciation of their newly acquired assets in addition to the risk of physical health, the residents questioned governments' scientific claims and presented counter-evidence with their scientific and engineering professional skills based on their voluntary web-based research. (Lang and Xu, 2013)

Compared to the cases in Beijing and Guangzhou, the Wujiang case seemed more militant. Lacking political and media connections possessed by their big city counterparts, the protesters in Wujiang city chose anther strategy – mass mobilization that overwhelmed the capacity of the local government to repress it and forced the government to close the plant rather than risk further turmoil. (Lang and Xu, 2013, p. 842) However, as Lang and Xu identified in their article that the success in Wujiang which was based on direct confrontation against the government was an exceptional case because similar regional small scale mass-protests were easily suppressed when the first generation of incinerators were installed in China in the 1990s. (Lang and Xu, 2013)

According to Lang and Xu, elite participation and the manipulation of the internet both in terms of voluntary research and as tools of arousing public and governmental attention constituted the major success factors of Chinese environmental movements. These successful patterns can also be traced in other types of Chinese environmental activism, such as the environmental NGOs.

In many respects, Chinese contemporary environmental governance shares some common features with the industrialized countries. In recent years, China's environmental policy has shifted from the end-of-pipe mode of pollution control to a more active mode of environmental management. The transformation in 2008 of the State Environmental Protection Agency (SEPA) – a governmental body affiliated to the central government – into the Ministry of Environmental Protection

(MEP) – a constitutional part of the central government – which indicated a strengthening of power in environmental policy making and implementation at the central government level manifested this trend of political reform concerning environmental protection. Despite this institutional reform which followed the Western model, the distinctive feature of China's environmental governance from the Western model might be interpreted from the roles of the civil society in environmental governance. Environmental NGOs in China played a supportive instead of a corrective role of Chinese environmental policy implementations. (Carter and Mol, 2006) In the sense that national scale indigenous environmental NGOs were treated as policy evaluation entities in society. Their major tasks were focused on providing positive feed-backs of environmental policy implementations and the enhancement of citizens' environmental consciousness. This indicates that only this type of environmental NGOs with a focus in line with the utilitarian perception against them held by the government might be able to get their public – largely government – recognition.

Government recognition of environmental NGOs in China is expressed by NGO's registration mechanism. According to their registry status Chinese environmental NGOs can be classified as GONGOs – government organized NGOs – and grassroots NGOs. (Wu, 2013 and Xie et. al, 2010) Most of the grassroots NGOs in China found it hard to be registered as non-governmental organizations. Instead they chose to either register as a business company or to simply avoid any form of registration and function instead as a kind of a loose social network. (Wu, 2013) The difficulties of getting legitimate organization status have generated several limitations to grassroots NGOs' developments, among which the source of funding and the problem of public credibility became the most obvious. Thus, as Wu (2013) pointed out, these grassroots NGOs had to choose to work with GONGOs or international environmental NGOs to solve their problems of financing and to legitimate their work. Such a situation implied that their scope is highly restricted to local affairs. From Wu's interviews with 9 grassroots environmental NGOs in Guangdong Province and 4 in Guangxi Province in Southern China, their focuses were mainly community environmental education or local scale natural conservation. (Wu, 2013)

Compared to the grassroots environmental NGOs in China, GONGOs seem to be in a better situation. First and foremost, winning governmental registration as non-governmental organizations not only gives them legitimate status but also more importantly gives them possibilities to participate in the official environmental politics in China. Friends of Nature (FON) established in 1993 and maintained as probably the most influential indigenous environmental NGO in China, is a prominent example of this type of environmental NGO. (Xie et. al, 2010) In political respects, FON is better in getting access to China's political institutions compared to most Chinese NGOs. Such an intimate relationship with the government gives FON a chance to organize cross-regional environmental protection projects and activities, not just restricted in Beijing where it is registered. One of the NGOs that Wu (2013) interviewed in Guangdong province is in fact a subsidiary of FON in Shenzhen City. That is to say FON was capable, from an organizational point of view, to organize national scale environmental protection activities. In spite of this, it seems that FON in Beijing provides funding resources to its Shenzhen subsidiary. In this regard, FON is an organizationally sound NGO rather than a loose network solely based on voluntary membership, or a relatively flexible consortium which might include multiple independent organizations. (Wu, 2013 and FON Website1, Accessed Mach 12, 2014)

FON's superiority derived from its founder. Liang Congjie (1932-2010), grandson of the famous late 19th century Chinese reformist Liang Qichao (1873-1929), son of Liang Sicheng (1901-1972), contemporary Chinese architect, the founder of the school of architecture in Tsinghua University in 1946, was a member of the standing committee of Chinese People's Political Consultative Conference (CPPCC) when he founded FON. Liang Congjie's higher education was received in new China from 1949 to 1953. He studied history in Tsinghua University. In 1953 due to the reform in Chinese mainland's higher education system, Tsinghua University was designated into a scientific and technical university. The department of history in Tsinghua was combined into Peking University which was at that time characterized as a liberal arts university. He received his bachelor's degree in Peking University and later his Master's degree in 1958 in the same university. After that he became a university professor in Yunnan Province in China. During the Cultural Revolution, Liang Congjie was one of the many intellectuals who were sent to the countryside to receive their "proletarian" education. When the Cultural Revolution faded away, he came back from the countryside to Beijing and gradually reclaimed his family's reputation and his personal career. (FON Website1, Accessed, December 3, 2014)

Nothing was said on the FON webpage on how and why Liang Congjie decided to devote his later life to China's environmental protection. Therefore, I can only conjecture that such a motivation derived from his personal reflections on Chinese culture and perhaps his social networks with other Chinese liberal arts academics. That might be the reason why when FON was founded it was also a part of the International Academy for Chinese Culture (IAFCC) which is a Peking University based GONGO dedicated to the research and development of Chinese culture – traditional Chinese culture to be precise. FON constituted as IAFCC's Green Culture Institute, and Liang Congjie served as its director. (FON Website1, Accessed 2014 December 3, 2014 and IAFCC Website1, Accessed December 3, 2014) It seems that Liang Congjie shared some common visions with his former colleagues and mentors in Peking University such as Feng Youlan and Ji Xianlin – all of them were prestigious Chinese scholars in philosophy and liberal arts – and thus they attempted to establish IAFCC as an academic research network in 1984.

On the IAFCC's webpage, FON's (the Green Culture Institute of IAFCC) work was described as the following:

> "to conduct public environmental education and development, to advocate green civilization and to spread consciousness of environmental protection among the public" (IAFCC Website1, Accessed December 3, 2014)

Liang Congjie's position in CPPCC permitted him some channels to get access to China's environmental policy making. Therefore, when FON was founded his personal connections to the governmental institutions could be directly appropriated by this NGO. However, from the tenets of FON's work, it seemed that such an appropriation of Liang's personal influence was quite modest. As a matter of fact, I tend to conclude that without Liang Congjie FON might not be founded and perhaps his influence on Chinese environmental activism was inherited from his family's reputation, even though there was no documented literature that gave such kind of direct correlations. But what is certain is that grassroots environmental NGOs have little in common with Liang Congjie's organization.

Liang Congjie passed away in 2010, but FON's participation in Chinese environmental politics has continued. According to FON's latest press release in October 2014, FON participated in the drafting of China's judicial interpretation of environmental civil litigation. (FON Website3, Accessed December 3, 2014) Obviously, participation in such an occasion is not an honor which can be shared by grassroots environmental NGOs, among which a large number of them, from a legal point of view, do not exist.

Another typical GONGO which could reflect some features of Chinese environmental activism is the Beijing Global Village Environmental Education Center (BGV in this thesis). The founder of BGV is Liao Xiaoyi. Born in 1954 Mrs. Liao completed her entire education in socialist new China. Compared to Liang Congjie, Mrs. Liao belongs to the younger generation of Chinese public intellectuals. She was educated as a philosopher in China with her undergraduate and postgraduate educations in Chinese universities. From 1993 to 1995 she worked in North Carolina State University as a visiting scholar, and after that she came back to China and established the Beijing Global Village Environmental Education Center. (BGV Website1, Accessed December 3, 2014) The early 1990s were the time when the concept of non-profit organization began to be introduced into China from the West. Before the economic reform it is hard to distinguish for-profit and not-for-profit organizations in China, because profit itself is a capitalist notion, but as the market economy has been developing in China for more than a decade, the concept of profit regained its meaning in the Chinese society. Influenced by Western environmental activism Liao started to combine the concept of non-profit organization with environmental activism. During her years in the United States, Mrs. Liao made a documentary about environmental issues and focused on global environmental politics and public relations related to environmental issues. Thus during the first a few years of BGV, her focus was on public education via television programs and popular publications. From 1999, BGV started to collaborate with Beijing city government to promote green behavior in the communities and it was in the year 2000 when Beijing started to compete for the hosting of the 2008 Olympic Games BGV was chosen to be its environmental consultant. Such a series of collaborations with the public media and government brought Liao and her BGV some public attention which led to their following projects. Most noticeably, BGV started to focus on sustainable energy issues in 2003. From 2003 to 2013 BGV established a forum for public debates about sustainable energy. According to BGV 46 meetings were held and participants ranged from technical experts, governmental officials and some general public attendants. 40 to 120 participants were invited in each meeting and BGV documented the content of each meeting on their website. In parallel to this public forum of sustainable energy, BGV also hosted an environmental journalists' salon which aimed to enhance peer communication among media professionals. (BGV Website2, Accessed December 3, 2014) However, as I can read from their 46 reports, nuclear power seemed not to be a major theme in their discussion.

BGV and FON had collaborations in their energy related projects, specifically a propagation project of advocating energy saving by advising that 26 centigrade as the proper indoor temperature in offices and private homes in summer. In fact such a nationwide propagation project was an advertisement of the central government's semi-regulatory advice concerning air conditioning usage in governmental offices to the broader public spaces started in 2004. (BGV Websites1, Accessed December 3, 2014) However, unlike the collaboration of grassroots environmental NGOs with FON which relied on the dependence of financial support, the collaboration between BGV and FON on this project of energy saving seemed much more like a voluntary consortium with an aim to extend public influence.

Both BGV and FON addressed the role of Chinese traditional culture to solve environmental problems in China. However, their approaches differed. FON focused more on the philosophical and aesthetic aspects while BGV focused on the issues related to public hygiene. Bird watching, mountain climbing have been the classical environmental awareness education programs of the FON with an environmental conservation attention, while a more community based BGV emphasizes the reclamation of some Chinese traditional habits to improve personal physical health such as their small scale organic farming projects in rural areas. (BGV Website3 and FON Website4, Accessed December 3, 2014)

In general, Chinese environmental NGOs work with the government instead of against it, largely due to the fact that the government control over society is still pervasive. From a sociological point of view, making environmental activism a profession in China is rather difficult. Unlike what Jamison depicted that environmental activism has gradually become professionalized in the West. (Jamison, 2001 and 2013) the situation in China is quite different. The professionalization process has never been started in China or it just represents a reverse path compared to Jamison's observations. In order to reach public credibility and to gain influence, the organizers of NGOs had first to be professionalized in other social domains not necessarily in environmental protection. The more connections with Chinese official politics the more likely their activism would be acknowledged by the government thus more resources could be mobilized for advocating environmental awareness in the Chinese society.

Chinese environmental activism is largely based on voluntary participation. Both FON and BGV can be categorized as civic voluntary groups. For instance both of them emphasize the recruitment of members and many of their routine projects are performed by their members. The establishment of such NGOs largely relies on the will of their founders, as does the participation of their anonymous members. In this regard, it is more appropriate to focus the study of environmental activism in China at the personal level, instead of treating it as a sort of social movement in a political sense such as the Cultural Revolution. Such a focus is especially important for the study of the cultural side of nuclear power engineering because as far as I am concerned, it is a relatively absent topic of environmental activism in China, however, we might deduce from various publications in the West that it should in fact be a core topic. Therefore, in this thesis the cultural reflections of nuclear power engineering is rendered as a series of studies on individual engineers inside the system, for that might be a better approach to get access to some insights into this complicated topic.

2.3. CULTURAL REFLECTIONS ON NUCLEAR POWER

In this chapter I argued that a pro science and technology culture in contemporary Chinese society is reflected in the dominant utilitarian view of science and technology in the shaping of China's science and technology policies and pays less attention to science and technology's cultural or social repercussions. However, these repercussions of science and technology development can be seen in various forms of environmental activities in China. The major site where academic studies about science technology and society are performed is the philosophy of science and technology departments in Chinese universities and the mainstream discourse remains pro science and technology. There are some intellectuals with liberal arts backgrounds who have shifted their attention from academic studies to environmental activism and achieved some success in advocating environmental consciousness. Due to a strong government control over the emerging civil society, Chinese environmental activism has to focus on those topics which seem to be closely related to everyday life in which common people possess more power. Nuclear power which represents complicated technology and is normally built far from populous areas is remote from the public debate about its environmental and social consequences. Lack of access to decision making and insufficient credibility – from a scientific perspective – could also be the reasons for the low level of public discussion. As a result, it seems that cultural reflections on nuclear power engineering could only be found within the system.

In 2012 He et al. based in the Chinese Academy of Science did a questionnaire field study in Shandong province after the Fukushima accident and depicted a general picture of the public knowledge, attitude and trust of nuclear power in China. According to their study, China can be characterized as a pro nuclear power country, due to the fact that both the government and the industry are supportive to the development of nuclear power, while public participation has not been influential in the decision making process related to nuclear power. (He et al., 2014)

The basic landscape of Chinese public knowledge and attitude about nuclear power can be illustrated by the following numbers. More than 80% of the respondents in their research started to pay attention to nuclear power and radiation related risks only after 2011 and such a growing amount of concerns was largely attributed to the Chinese media which widely reported the nuclear disaster in Japan. But knowledge about earlier nuclear disasters such as the Chernobyl and the Three Mile Island accident was dramatically less. Among those who have some knowledge about nuclear risks only 20% claim that they know something about nuclear power technology but 60% of them have even less knowledge about the technology. In addition, very limited knowledge among the respondents about the policy and management of nuclear power plants was identified. When the respondents were asked about their attitude toward new construction of nuclear power plants, 33% expressed a supportive view; another 33% expressed a negative view, while 29% had no opinion. These figures show that the major players in Chinese nuclear power construction plans are restricted to the government and the nuclear power companies which are all state owned enterprises. Even though pro nuclear power and anti-nuclear power public attitudes seem evenly distributed among the general public, such views are not closely related to the decision-making. Normally it is the government's persuasion founded on depicting nuclear power as a resolution to the increasing energy demand triggered by rapid economic growth and population growth, and to mitigate air pollution that determines the discourse about nuclear power. (He et al., 2014)

In China's nuclear power politics, the central government plays the role of planning and providing legitimacy – in terms of licensing – of nuclear power development. The nuclear power companies are in charge of policy implementations, while the local government treated the construction of nuclear power plants as an opportunity to further economic development. (He et al., 2014) Such a structure of nuclear power politics can be traced in the National Development and Reform Commission's (NDRC) Medium and Long-term Nuclear Power Development Plan proclaimed in 2007. This ambitious plan indicated that by the end of the 12th Five-Year Plan (2011-2015) period 25 GWe of new capacity is planned to be operational; 45 GWe may be added by the end of the 13th Five-Year Plan. State owned enterprises such as CNNC, CGN, and SNPTC are the implementers of this plan. (Zhou et al., 2011)

The Fukushima accident caused a comprehensive safety check of all nuclear power projects, including those which were under construction, but all signs showed that it was just a temporary hold of China's plan to acquire more nuclear power. (Thomson, 2013) In May 2012, a new 12th Five-Year Plan and the 2020 Vision Goals of Nuclear Safety and Radioactive Pollution Prevention and Control were approved in respond to the Fukushima nuclear crisis. (Thomson, 2013) This new plan is an adjusted version of the five-year plan published in 2007, which restricts new plant constructions at inland sites while still permits new plant constructions in coastal areas. Like the old plan, this new plan was made in a closed policy community including only the government and the industry. (He et al., 2014)

According to He et al. (2014), the Chinese public trusts the government more than nuclear power companies, but less on environmental NGOs. It is only among the higher educated citizens that NGOs' information about nuclear power plant is considered as reliable and trustworthy. (He. et al., 2014) However, there exists some distrust of the government and nuclear power operators such as in 2007 some Internet bloggers pointed out that the MEP had not issued an Environmental Impact Assessment (EIA) for the Rushan – in Shandong Province – project prior to the official announcement of the project. A couple of national media networks picked up the news and triggered an intensive local debate about the project. More recently the lack of domestic reporting on a small scale radioactive leak inside the nuclear island in the Daya Bay plant on 23 May 2010 illustrated that transparency and communication with the public on nuclear issues is not really improving in China. (He. et al., 2014)

Perhaps, due to the fact that Chinese operators, up till now, gained a relatively safe record, (Thomson, 2013) the Chinese general public's concern about nuclear power seemed to be focused on the transparency of nuclear power plants' operation rather than a questioning of the inborn risks of nuclear power technology. The only serious discussions about the pros and cons of nuclear power technology are carried out among the scientific and engineering professionals in China.

Gu et al. (2006) – nuclear scientists in China Institute of Atomic Energy – in their article Strategic Considerations on Development of Nuclear Power and the Associated Fuel Cycle in China, published in 2006 proposed a strong pro-nuclear position:

> “China has an ambitious program to develop her nuclear energy in the coming decades so as to ensure the sustainable development of national economy of the country.” (Gu et al., 2006, p. 965)

> “In the coming 30 years or so, PWR is selected as the main reactor-type of NPPs and Gen-3 PWRs will be the leading units of NPPs in China. With this goal in mind, we will quicken the pace of developing the technologies of Gen-3 PWRs with our own efforts while actively joining the international cooperation.” (Gu et al., 2006, p. 966)

> “As a developing country, China’s technologies on nuclear fuel cycle lag behind the world advanced level. In the front end of the fuel cycle, China has established her industrial production capabilities. But the technologies need to be up-graded and the scale needs to be expanded. The back end of the fuel cycle in China is the weak point of the whole nuclear fuel cycle owing to the insufficient investment in the past decades. We have to pay more attention to and strengthen the R&D work in the back-end of the fuel cycle and build a complete fuel cycle industry, so as to meet with the requirements of sustainable development of nuclear power in China.” (Gu et al., 2006, p. 966)

Such words can be understood as describing the tenets of the pro nuclear power culture among scientists and engineers in China. First, nuclear power is related to sustainable development and economic growth, in which environmental concerns are abbreviated to tidy up the mess of nuclear waste. That is the reason why in their perceptions the back end fuel recycle technology shall be given greater emphasis. Second, the idea of catching up with advanced foreign technologies appeared, which is not quite new in the language of Chinese scientists and engineers. As far as I am concerned, it is a consequence of the utilitarian view of science and technology. Since advanced technology is considered as more efficient, it must be of higher utilitarian value. That is the reason why Chinese engineers – at least in the nuclear power industry – are craving for the most advanced technology such as the Gen-3 PWR technology mentioned in this article. Third, increasing financial investment to R&D activities is regarded as a positive factor to the upgrade of technology and engineering research capacity. In this respect, scientific and engineering research is expected to set up an even closer relationship with the state and the industry; as such a research-state-market complex can be constituted. With this mechanism, it is believed that China’s self-reliance on Gen-3 nuclear power technology can finally be achieved. And importantly, it is implicated that Chinese people will benefit from these efforts.

However, not all the nuclear scientists and engineers in China give a straightforward support to the development of nuclear power. He Zuoxiu, one of China’s first generation nuclear physicists, a Tsinghua University graduate is one of the most prominent figure among those who reluctantly accept this source of energy. He Zuoxiu was born in 1927, and studied nuclear physics in Tsinghua University in the 1950s. After his graduation, he participated in China's nuclear physics military research; he was elected an academician of the Chinese Academy of Science in 1980. (CAS Website, Accessed December 4, 2014) Despite of his work in nuclear physics research, in his later years he turned to be a professor of dialectics of nature – Chinese philosophy of science – in Peking University in 1984. In the second national meeting of Chinese Society for Dialectics of Nature (CSDN), in the year 1992, He Zuoxiu was elected one of its executive directors. In recent years, He Zuoxiu devoted his life to the advocacy of the humanistic spirit of science – in his own term – which can be read from his publications in some Chinese newspapers such as the Xinhua Daily (2008-01-16) and other internet based interviews such as an interview by SINA.com.

He became an active internet blogger (He Zuoxiu's blog: http://hezuoxiu.blogchina.com/index_1.html, Accessed December 4, 2014) offering his opinions about China's nuclear power development. From his internet articles, it can be read that he is a persistent protester of constructing inland nuclear power plants. His argument, according to him, is not anti-scientific but authentically scientific. For example, he criticized the hypothetical methodologies used to justify the intrinsic safety calculations adopted in nuclear power plant's design. According to him, science and calculation are not omnipotent, because there are some natural disasters which cannot be precisely predicted such as the tsunami in Fukushima. More critically, he made some ironic comments to show that the current scientific calculation on nuclear safety is rather misleading. Designers claim that the probability of severe accident in one reactor year is at the level of 10^{-7} to 10^{-6}; however, taking into the consideration that up till now there are no more than 500 reactors under operation throughout the world but we have experienced at least 3 severe accidents, it seems that our scientific predictions dramatically underestimated the real probability of severe accidents. Since inland nuclear power plants require a huge amount of cooling water for their normal operation and even more emergency reserves, and we cannot predict the frequency of severe drought which seems to be more frequent in recent years in China's inland areas, inland nuclear power plants' safety for him cannot be ensured.

In some interviews, He Zuoxiu was opposing the booming development of Chinese nuclear power. He made an analogy of the rapid approvals of China's new built nuclear power plants started from 2008 to 2011 to the Great Leap Forward in the late 1950s, which he thought was largely un-scientific. He pointed out that nuclear power plants can only be built in coastal areas where cooling water is abundant and are thus safer. He also criticized that nuclear power companies' lobbying for inland nuclear power plants was derived from a mindset of market competition regardless of the consequences. In still other interviews, for example the one reported by hexun website (http://news.hexun.com/2011-04-08/128583781.html, Accessed

December 3, 2014) in April 2011, almost immediately after the Fukushima accident, he said that atomic energy shall only be used for limited specific purposes, as for the mass production energy for civil use, he preferred hydro, wind or solar powers. But in 2012 when he updated his blog, such expressions were not written down.

It is difficult to establish a connection between He Zuoxiu's personal opinions and the newest Chinese nuclear power policy which clearly restricts new construction of nuclear power plants at inland sites. In the sense that I cannot evaluate or even know whether He Zuoxiu had made some contribution or even was involved in the making of this new plan. But certainly his blog aroused some social repercussions in the sense that many of his internet articles were transmitted by other bloggers and his opinions were opposed by the promoters of nuclear power in China. He is an established Chinese scientist and his approach of making his argument is largely scientific such as his expression of nuclear radioactive release risks in a formula. It seems that he is officially tolerated by the government, therefore, for better or worse, his voice can be heard by the general public.

He Zuoxiu never claimed himself to be an environmentalist. He might be a physicist turned philosopher; in any case, he held a prestigious profession when he unwittingly participated in the Chinese environmental activities against nuclear power. Anti-nuclear power activism might be a very difficult area that environmental activists are able to tap into, even for Liang Congjie or Liao Xiaoyi. But their participation in the broader sense of Chinese environmental activism shared some common feature, which is before their involvement into this unstable public space – either intentionally or unwittingly – they have been professionally successful. Without a fear of losing the way of making a living in society which might be caused by some politically incorrect expressions or actions, they practiced some moderate critiques to China's science and technology policy and its mode of economic development. Their experiences hold some positive meaning in that from them the new generation of Chinese scientists and engineers feel that the social status of Chinese intellectuals has now been changed in the post-Mao era. Although we may still face some risks against our career development in case of expressing opinions contradictory to our employers' policies, other than that there is no limit for us to participate in the various forms of environmental activities in China, for example to become a member of FON.

Chinese environmental activism, from my perspective, is largely an individual phenomenon which means that it is closely related to personal lives. Importantly, like it is in the West, performing a cultural reflection on science and technology development shall be counted as a major part of environmental activism in China. The Chinese feature of environmental activism, in this respect, especially when the tenets of this type of cultural reflection praxis relates to nuclear power engineering, is that Chinese scientists and engineers cannot choose to be an environmentalist as a profession. That is to say their praxis pervades their work, lives, hobbies, and casual talks. We cannot expect that all these forms of praxis would generate broader social repercussions or impacts like the practices of the prestigious people. In fact some normal engineers and scientists intentionally avoid bringing about such repercussions, and prefer to be unnoticed. But I would say that they remain active silently, therefore, researchers, like me, who intend to study this silent environmental activism about nuclear power engineering in China, shall take all these clues into consideration because all these seemingly minor factors are highly relevant to the means and ends of making changes to the engineering practices in a nuclear power engineering company in China.

CHAPTER 3. CGN'S GROWTH AND ITS ENGINEERING DESIGN SYSTEM

3.1. FROM A POWER PLANT TO AN ENGINEERING COMPANY

China General Nuclear Power Group – CGN as its official abbreviation – developed from a nuclear power plant situated at the coast of Guangdong Province in southern China. The power plant got its name from the name of the place where the two nuclear islands were constructed, Daya Bay. From a historical point of view, the establishment of this nuclear power plant symbolized China's civil use of atomic energy that starts in the 1980s. Taking the historical cultural background of this engineering project into consideration, the Daya Bay nuclear power plant engineering project is an exemplary project in the history of China's science and technology development because from my point of view it reflected both the traditional and the contemporary Chinese engineering experiences.

The traditional side of the engineering experience of this project refers to the habits of engineering in the Chinese culture. First, as it was manifested by the Daya Bay project, large scale engineering projects were often related to the state's political ambitions. In pre-modern China, the most well-known Chinese engineering feat, the Great Wall was designed and constructed for the political purpose of preventing the Chinese agricultural civilization from the invasion of northern nomadic peoples. (UNESCO1, Accessed August 9, 2015) In this respect, it was not a coincidence that the nuclear power plant project derived from a pursuit of China's self-reliance on massive scale centralized energy supply. This pursuit seemed to be urgent in the 1970s and 1980s when the energy crisis became a global issue. (Thomson, 2013)

Second, the intimate relationship of Chinese infrastructural engineering practices with politics indicated some habits of the human or social aspects of engineering in China, especially on its leadership and organizations. The Dujiangyan irrigation system located in Sichuan province built in the third century BC is perhaps the primal case that can be traced on the establishment of these engineering habits. (UNESCO2, Accessed August 9, 2015)

The Dujiangyan project was led by the governor Li Bing of the Qin Dynasty during the Warring States period (406-221 BC). (UNESCO2, Accessed August 9, 2015) From a contemporary perspective, the planning of this project was not entirely an irrigation system in the sense that the choice of technology was in fact largely shaped by political concerns. Before the Dujiangyan system was built, farmers living along the banks of the Min River were annually troubled by flooding. One solution of this problem would have been to build a dam, but Li Bing as the governor of this region had also been responsible for keeping the waterway open for military transportation, therefore instead he decided to construct an artificial canal to redirect a portion of the river's water flow in order to channel the excessive water for irrigation purposes and keeping the vessel transportation open at the same time.

In the year 2000, the Dujiangyan site was listed by the UNESCO as a World Heritage located in China, representing its cultural and physical significance. In this thesis, I tend to think that its cultural influence might be more persistent in contemporary Chinese engineering than its technological legacy. Because it seems to be quite obvious that some common features between this ancient infrastructural project and its contemporary counterparts such as the Daya Bay plant exist. The nuclear power plant project from its planning stage was led by government officials instead of business elites as it was often the case in the West. From former premier Li Peng's Diary (2004) published after his retirement, the Daya Bay project consisted of a major part of his work from the 1980s to the 1990s concerning the development of nuclear power in China. In his diary, as he recorded, many important decisions such as the allocation of the plant and the choice of technology were finally decided by the central government and more importantly the announcement of the determination of building the Daya Bay plant with French nuclear power technology was made by China's top leader Deng Xiaoping. Provided that we can compare the cultural perceptions on science and technology in China over history, the utilitarian view over this type of knowledge seems to be evident and long lasting which can be expressed in another way that this utilitarian perception of engineering might serve as one part of Chinese traditions.

Engineering, especially infrastructural engineering, has long been a state enterprise in China, which can be verified by the origin of a governmental organ called gong bu which can be literally translated as the Ministry of Work[11] in English. This governmental organ first appeared in the Zhou Dynasty (around 11 century BC to the end of the Warring States period in around 2 century BC) and was kept constant to the last feudal dynasty – Qing Dynasty (1644-1911) – in China. For thousands of years, this government department managed infrastructural construction projects over the territory of the Central Kingdom, including for example the irrigation projects and the military projects such as the Great Wall. As the modernization processes preceded in China especially in the late period of the Qing Dynasty the function of this governmental department extended. In addition to its traditional tasks, gong bu was given the authority of supervising machine making, mining, industry development activities especially those engineering activities related to the military. (Zhao, 1990 and Zhao et al., 2002) Nowadays, in the current structure of

[11] As it was translated by Joseph Needham, in page 27, in The Grand Titration – Science and Society in East and West, 1979.

China's central government the traces of gong bu still exist. It is just that this omnipotent department was dismantled into some smaller parts and each became an independent governmental department of its own, such as the Ministry of Industry and Information Technology, the Ministry of Water Resources, the State Administration of Science Technology and Industry for National Defense, and the Ministry of Transport etc. In this respect, the professionalization of China's modern engineers started from the public sector instead of the private sector. This tradition was also inherited by the Daya Bay project in the sense that this project was from its origin a state directed and owned business.

Another relatively newly emerged Chinese engineering habit which served as an intermediary between the traditional and the present Chinese engineering practices, refers to the notion of "learning from the West". This indicates that Chinese engineering projects in its modernization process were often related to China's interactions with Western industrialized countries and the Daya Bay project was no exception. Even though the idea of building a nuclear power plant in the relatively affluent coastal provinces of China emerged long before the 1980s and the negotiations concerning the Daya Bay project had been started in the early 1980s, the contract which symbolized the final planning of the Daya Bay plant was not signed until the Sino-British negotiation over the sovereignty of Hong Kong had been finally settled. (Yee, et al., 1987) Two years after the signature of the Sino-British Joint Declaration on Hong Kong, in 1986, representatives from Guangdong Nuclear Power Joint Venture Company (GNPJVC), the French – the nuclear island – and British – the conventional island – suppliers signed the key contracts governing the construction of the Daya Bay nuclear power plant. (Zhan et al. 2003) In this respect, the project is a demonstration of mainland's future economic contributions to Hong Kong which would foster Hong Kong's stability and prosperity. (Yee, et al., 1987) Relating the Daya Bay project to the policy of "opening up", Deng Xiaoping's words after his meeting with the chairman of CLP group – China Lighting and Power Company, a Hong Kong based electricity generation company – on January 19th, 1985 recorded by Xin Hua News Agency's newsletter made a clear illustration: "Adopting the opening up policy will allow something of capitalist origin enter China. But the socialist power is stronger, and will achieve greater development. The ratio of socialist power will always remain dominant." (Li 2004) Deng Xiaoping's words, from a political perspective, legitimated the Daya Bay project including its incorporation of Western capital and technology.

According to the contracts the Daya Bay project was designed to be a turn-key project which meant that it was the French and British suppliers' – mainly the French company Framatone – responsibility to guarantee its technical success and nuclear safety in technological terms. Chinese involvement in this project was delineated to construction support and follow-up operation and maintenance after the selected Chinese operators received training in French plants. Engineering design and equipment manufacturing were not in the scope of the Guangdong Nuclear Power Joint Venture Company (GNPJVC) which served as the owner of the company. (Zhan et al., 2003) Thus, "learning from the West" in the Daya Bay project could only be interpreted as learning how to operate.

At the time when the Daya Bay project was built, another nuclear power plant Qin Shan Phase 1 project in Zhejiang province at the eastern coast based entirely on Chinese technology was also under construction. (Li, 2004) In this respect, the Qin Shan project represented China's transformation of its previous military atomic scientific research and development to civil use of nuclear technology on a relatively complete self-reliant approach while the Daya Bay project seemed to follow the approach that had been set up by the previous modernists back in the late 19th century – technology transfer. Such a difference on the development of technology indicated a different path of growth between CGN and CNNC – China National Nuclear Corporation which is still a nuclear military industrial complex – especially on the perceptions of engineering design.

From a commercial perspective, the Daya Bay project can also represent some contemporary trends of science and technology development with its origins rooted in China's long modernizing processes and in the pre-modern criticism about technology and engineering. Even though quite scarce, there were still some well-known records about China's original cultural and social objections to engineering and technology in its long history. Nevertheless, the motifs concerning the cultural evaluation of engineering projects changed over-time.

Perhaps the most evident social comments related to these engineering projects referred to the issue of abusing human labor, such as the case related to the Great Wall. The Great Wall was initially constructed by various independent feudal states in the Warring Period. It was the first Chinese emperor Qin the First, who connected these initially separated defense facilities into a whole system after his conquest of the last 6 states. (UNESCO1, Accessed August 9, 2015) In order to accomplish his feat, the emperor manipulated hundreds of thousands of human laborers which might serve as one reason for the fall of the Qin Dynasty. According to one of the Chinese legends, Madam Meng Jiang, whose husband was enlisted in the huge labor force but unfortunately died due to extreme hard labor, went to the construction site to find her husband without knowing that her husband would never return. After hearing this heart breaking news, she cried incessantly and her tears led to the collapse of a section of the Great Wall. (Idema, 2012) This legend has been passed down for generations as a criticism of this ancient Chinese engineering project in the name of a crime committed by the emperor. Even though Chinese people acknowledged the protective function of the Great Wall to their peaceful agricultural lives, its destructive effects were also revealed. However, negative records related to the Dujiangyan project are not found. Therefore, I can only deduce that ancient Chinese history commentators evaluated the cultural and social consequences of engineering projects by balancing both the positive and negative impacts on human lives. Life and death served as the most direct concern in the pre-modern Chinese assessment of technology, in the sense that, provided that the positive aspects outweighed the negative, such engineering projects would be regarded as favorable.

It was in China's initial industrialization process in the late 19th century that strengthening national defense became the major criterion of the cultural and social evaluations of engineering. The modernists believed that Western technology would serve as the new Great Wall to protect Chinese people to live as their ancestors without interference from other civilizations. In addition, to strengthen its military power, national wealth would serve as its foundation. In this mindset, industrial development began to take root in China, for instance the construction of railroads which were considered as both positively effective to national defense and civil transportation of wealth. Comparing this view of engineering and technology to China's pre-modern values, it seemed that commercial value had started to be added to engineering and technology from this period of time. At the same time, the protesters of modernization not only objected to the introduction of Western science and technology but also saw them as a threat to Chinese civilization instead of a protective force.

In 1876 when the first railroad in China was built in Shanghai, a fierce opposition toward this industrial development appeared with the argument that rail roads would not only corrupt the agricultural land, but also entice people to admire material benefits by trading rather from production. At the time when the traditional value system outweighed the modern understanding, such a social objection led to the dismantling of the already built first Chinese railroad. In 1880 when Governor Liu Mingchuan, attempted to build another railroad in Taiwan, he experienced a similar situation. The imperial court indicated him that his attempt was not in compliance with patrios nomos. (Jin et al., 2003) In the cases of the failures of early railroad development, no matter what the difference between the opposing rhetoric expressions, the hidden meaning was always to detach engineering and technology from commercialization which in fact was one of the triggers of the industrial revolution in Europe.

However, 100 years after China's initial attempts of modernization, the entire ambiance toward science and technology has been fundamentally changed which from my perspective contributes to the success of nuclear power development. The essence of this round of transformation can be characterized as the combination of science and technology with commercialization, on one hand, and the detachment of it from the notion of national defense on the other. Such a transformation gave the advocates of nuclear power apparent advantages dealing with social protests against this technology.

First, detaching nuclear power from military technology impeded people's imagination of this technology with war thus easing the tension of life and death related to this technology which might still exist in Chinese traditional images of engineering projects. Second, a closer relationship of engineering and business gave the government who made the entire plan a better position. It can be interpreted from the commercial angle that nuclear power is a lucrative business for the common good. Even though the planner might not deny its risks, it is much easier to transfer the tough question of balancing the merits and demerits of this technology to the general public and making the government an impartial third party with a benign intention. Third, making nuclear power a business instead of a political affair can better soothe the tension of importing Western technology which might indicate a sense of foreign technological and economic invasion. It seemed that the commercialization of nuclear power in China responded to all these perplexing dilemmas which were unsolved by China's previous attempts.

These might be the reasons, from a cultural perspective, why the Daya Bay nuclear power plant was from its beginning designed to be a joint venture between a legal person established by the Chinese government and the CLP group a foreign partner and importantly using the French technology because the French government agreed to export nuclear power technology to China without political prerequisites except a guarantee of the Chinese government not to use this technology on military purpose which was in fact at the beginning not intended. (Yee et al., 1987)

The dominant commercial culture triggered by the opening-up and economic reform policy permeated in China ever since 1978 may also explain why the Daya Bay project which was launched after the Chernobyl disaster could still be accomplished in China even with some protests which seemed to be no less fierce than the old railroad case.

The Daya Bay project was placed in a geographical site about 50 kilometers away from Hong Kong. According to the joint venture contract the Daya Bay plant would sell its electricity to Hong Kong CLP group after its commercial operation (Zhan et al., 2003). The deal would be liquidated by US dollar which would increase China's foreign currency reserve that was appreciated valuable at the beginning of its economic reform and at the same time would relive Hong Kong's shortage of electricity supply without building more plants in its territory (Li, 2004). In this respect, it seemed to be a win-win deal. However, the Chernobyl nuclear disaster ignited a rapidly growing environmental concern which developed into a social unrest in Hong Kong relating to the construction of this nuclear power plant (Yee et al., 1987). In a retrospect, its ending manifested the triumph of the preference of economic growth.

Some newspaper reports against the construction of the Daya Bay nuclear power plant helped to ignite an anti-nuclear power movement in Hong Kong, which from its beginning divided into three steams. There was the radical stream that insisted on a shelving of the Daya Bay project. There was the middle stream that suggested postponing this project until the fervent public opposition against this project cooled down. The weakest voices against this project said that they were not in the opposition of China's willingness to acquire nuclear power but the project just needed to be relocated to a more remote area from Hong Kong, as such they could even bear the additional cost of this relocation. Even though the anti-nuclear power media, such as the Ming Pao which was the most active newspaper in the movement, used wordings such as "dead-harbor" to successfully attract public attention of potential nuclear disasters, in their opponents' eyes these protests were not so difficult to be dealt with. (Yee et al., 1987)

The pro-nuclear power campaign was also started in the public media which served as the major battle field of the debate about Daya Bay nuclear power plant. Unlike the divided voices expressed by the anti-nuclear power campaigners, the pro-nuclear power professionals were more coordinated. First they reiterated that the point of departure of the Daya Bay project was from the good will of providing a foundation of Hong Kong's long term prosperity. In addition, they indicated that the Central Government in Beijing had already made a great investment into this project. Therefore, it was not an option that this power plant could be relocated. Second, the most effective strategy, from my point of view, was to argue that science and technology had been employed to shape the rational and reasonable image of the pro-nuclear power campaigners leaving those who claimed that the project held political meaning and who worried about nuclear disasters through qualitative deductions an irrational and unreliable image. (Yee et al., 1987)

After Beijing's commitment of receiving a long term transparent international monitoring over Daya Bay's future maintenance and operation, and an organized reiteration of the advancement of the technology adopted in Daya Bay which was fundamentally different from the Chernobyl plant in the public media, the opponents seemed to find their peace with a reluctant acceptance of this project. In many respects, the ending of this story seemed to be predicted by its beginning. Even at the beginning of the protests, there were heavily loaded economic concerns among the anti-nuclear power campaigners. Those who claimed a concern of the plant's threat to the political stability of Hong Kong emphasized its negative influence to Hong Kong's stock market in case a false alarm of disaster appeared on the market (Yee et al., 1987). It seems to me, a misleading appropriation of the human concern into economic terms led to its loss. As it was in the 1980s when science and technology had been more incorporated in economic development, it seemed to be a false strategy to use the knowledge of economy which was supposed to be another school of rational thinking to attack science and technology, because science technology and economy seemed to strengthen each other in many ways in reality even before this era.

From this brief overview of the debate about the Daya Bay project, I am trying to reach to a tentative conclusion that it was in the 1980s, after a long time of searching, China has finally found its way – perhaps shortcut to be more precise – to modernization. Opening-up and economic reform, serve as its rhetoric appearances while in fact the commercialization of science and technology consists of its core. This was what the first modernists had envisioned but not realized due to their misinterpretation of the function of science and technology in society in their times. From a contemporary perspective, the dominant cultural image about science and technology in Chinese society might be its connection to economic development. Such a connection can be interpreted in many ways. In regard to nuclear power science and technology, we may use the Daya Bay nuclear power plant project as the best demonstration. Consequently, it seems to be evident that this dominant cultural perception of science and technology indicates CGN's organizational growth after the Daya Bay project and its path to achieve the ability of engineering design. Especially from this point of departure we might be able to explain why engineering design was developed in the way as it appeared in CGN.

In 1994 the first unit of the Daya Bay nuclear power plant reached to its commercial operation and the second unit was accomplished in 1995 (Zhan et al., 2003). CGN's development after this demonstration project was well predicted by its planner, perhaps most famously by former Primer Li Peng. "To development China's nuclear power industry on rotational basis using the capitals accumulated from the previously built plants." (Li, 2004) This guiding principal served as the motif of CGN's transformations in its follow up nuclear power projects, and importantly from a retrospective, this concise sentence might explain the motives behind CGN's transformations both technically and commercially.

In 1997 the central government granted a permission to build another nuclear power plant just a few hundred meters away from the Daya Bay site named the Ling Ao Phase 1 plant. In general, the Ling Ao Phase 1 project was technically a copy of the Daya Bay project in the sense that the technology adopted in this later project was the same as its predecessor's. However, the major difference between the Daya Bay project and the Ling Ao Phase 1 project was that in the later project the owner of the plant was changed into a complete Chinese legal person instead of a joint venture. Technically, Chinese engineers were given more opportunity to participate in its engineering design and equipment manufacturing. Compared to the turn-key Daya Bay project which was a full scope procurement of foreign equipment and engineering services during the construction, the Liang Ao Phase 1 project adopted some moderate attempts of technology localization. 11% of the nuclear island equipment and 23% of the conventional island equipment was manufactured by Chinese domestic suppliers. In addition to that, the civil engineering design of the nuclear island was subcontracted to Beijing Institute of Nuclear Engineering (BINE). (Liu et al., 2003)

The Ling Ao Phase 1 project also triggered some organizational changes of CGN's project management. With the technical assistance provided by Electricite de France (EDF), CGN formed its technical management team, which performed some engineering design review tasks. The technical management team was under the rule of an engineering department. In addition to the technical management team with its official name as the technical management branch, there were several other branches included in the department, such as the procurement branch, the construction site management branch, and the testing and commissioning branch. All these branches used their English initials to distinguish each other. The E branch represented the technical management branch; the P branch meant the procurement branch; C represented the construction site management branch and S was given to the testing and commissioning branch. Thus EPCS together covered the major types of engineering practices in the engineering department of the Ling Ao Phase 1 project. (Liu et al., 2003) In fact such a division of labor was based on the understanding of the phases of a standard engineering project.

In CGN engineering design is put first as plan making. All the follow-up work is regarded as implementation, such as procurement which sources on the market available products that can satisfy the supposed functional requirements. When the materials and human resources are ready, it is the responsibility of site managers – engineers – to build the concrete and steel structures and install equipment. At the end of the construction and installation but before the start-up, tests are needed to ensure that the systems would function as they are designed. (CNPEC Engineering Training Center, 2010) This is the typical sequence of how a nuclear power plant be built. It was in the Ling Ao Phase 1 project, engineers from Chinese mainland started to participate in all these tasks because in the Daya Bay project some part of these jobs even in general and superficial terms were carried out by CLP engineers. (Liu et al. 2003)

Compared to the Daya Bay project, the Ling Ao Phase 1 project was a greater commercial success, because the entire construction took only 6 years, exactly as it was designed, without apparent delays. According to the official summary of this project published in the year 2003, the major reason for the smooth implementation of the project derived from the extent of the maturity of the technology which meant that no significant modifications – technical changes – were adopted in the Ling Ao Phase 1 project compared to the Daya Bay project. (Liu et al., 2003) However, another unwritten factor might be perceived from the social perspective. Due to the silence of the anti-nuclear power movements in both Hong Kong and mainland China after the accomplishment of the Daya Bay project, the Ling Ao Phase 1 project was implemented in a relatively peaceful ambience as if it was only an attempt of amplifying China's technology reserves to ensure its energy safety.

The decade from 1995 to 2005, was a relatively quiet period of nuclear power development in China. It seemed that Chinese energy policy planners were more interested in acquiring different types of nuclear power technologies than urgently putting one type of them into large scale application. In the 10 years, in addition to the Ling Ao Phase 1 project, there were three other projects implemented at the coastal areas in China. Two of them were situated at the Qin Shan site led by CNNC. The Qin Shan Phase 2 project after the Qin Shan Phase 1 project was based on a self-reliant design which was, to some extent, an improvement of the Chinese home grown nuclear power technology. The Qin Shan Phase 3 project was a project which adopted the Canadian heavy water reactor technology. The Russian technology had also found its market in China with the Tian Wan Phase 1 project launched in 1999 in Jiangsu province. Nuclear power became a demonstration of international energy technology cooperation in China, but there was no sign that any of these technologies would dominate the nuclear power market in China at that time and in the future. (Zhou et al, 2011, Thomson, 2013) As a matter of fact, compared to what happened after 2005 and especially in 2007 and 2008, the total market value of nuclear power was apparently smaller in these 10 years.

The real opportunity for the rapid development of nuclear power – the renaissance of nuclear power in China – appeared in 2005 when the China Nuclear Power Middle-Long-Term Development Plan 2005-2020 was officially promulgated by the National Development and Reform Commission. (Zhou et al, 2011) The plan[12] was written in five chapters with the first two chapters presented an overview of nuclear power development in China and worldwide. Importantly, in the second chapter a future development of nuclear power in China was scientifically and technologically legitimated upon two presumptions. The first supporting presumption was that China had gained enough technology and economic preparation from its self-reliant projects by CNNC and some international commercial projects such as the Daya Bay and Ling Ao Phase 1. The second presumption was that nuclear power was considered as knowledge and capital intensive industry on one hand, and a low carbon emission source of electrical power supply on the other hand. Therefore, giving it a preferential status would comply with the central government's determination of reducing CO2 emissions and maintaining or even strengthening China's industrial and manufacturing capacity at the same time. As such the foundation of China's economic growth and the progress of "modernization" would not be hampered.

In the following three technical chapters of the plan, technical or scientific methods of achieving the goal that by the year 2020 40 million KWh capacity of nuclear power would be installed were systematically written down. As a guideline, two

[12] SDPC Official Website, http://www.sdpc.gov.cn/nyjt/nyzywx/t20071102_170122.htm, He Dian Zhong Chang Qi Fa Zhan Gui Hua 2005-2020, China Nuclear Power Middle-Long-Term Development Plan 2005-2020, 核电中长期发展规划（2005－2020 年), (Accessed May 20, 2013)

parallel technology paths were identified which were again identical to the two modes manifested in the 1980s. One was the mode of self-reliant and the other was technology transfer. Issues such as investment feasibility studies related to nuclear power plant projects, site preparation and conservation, safety and reliability of nuclear fuel circulation, waste treatment and main equipment manufacturing were all included in this plan.

This plan brought up many changes in the Chinese nuclear power market and among these changes two seemed to be more significant. First, in 2007 a new player, the American Westinghouse Nuclear Power, had finally entered into this country which seemed to be impossible a few years ago. Along with the import of the Westinghouse AP1000 technology – Gen-3 pressurized water reactor technology in American standard – a new Chinese nuclear power company – the State Nuclear Power Technology Company (SNPTC) – was established in order to coordinate a national scale technology transfer of the AP1000 technology. (Zhou et al. 2011) Second, CGN caught up this opportunity to achieve its expansion from a nuclear power plant to a nuclear power complex. Such a transformation was achieved both technically and organizationally. Up till 2007, CNNC, CGN, SNPTC the three Chinese nuclear power engineering company had finally been shaped as a consequence of the plan. It also indicated that competition was successfully introduced to the Chinese nuclear power market. This explained why heavily commercial oriented growth strategy appeared in each of the three companies' policies.

What can be read from the 2005-2020 Nuclear Power Development Plan was that, there was no time in history like it was in the 2007 and 2008 that China was in urgent needs of nuclear power. Due to the high price of petroleum oil, an increasing burden of air pollution which became more and more serious in the big cities in China such as the capital Beijing, and the worldwide financial crisis originated from the United States, nuclear power – a stable, low cost, emission free – technology appeared to be the solution to all those problems. Importantly, cleaning the air by nuclear power as a replacement of the conventional coal powered plants would not induce economic regression. This interpretation about nuclear power seems to be a consensus among the majority of Chinese engineers and policy makers. It was in these circumstances, CGN established its own engineering company CNPEC in 2004, its design institute CNPDC in 2005 and its research institute CNPRI later in 2006. (CNPEC, 2013)

These three subsidiaries of CGN derived from the engineering department in the Ling Ao Phase 1 project for one purpose the Ling Ao Phase 2 project which was the most significant project for CGN because it was in this project CGN claimed its complete mastering of the French Gen-2 pressurized water reactor technology under its own Chinese brand CPR1000. (CNPEC, 2013) It meant that the newly established CNPEC together with CNPDC and CNPRI served as the lump sum contractor of the Ling Ao Phase 2 project instead of the French company AREVA NP – previously Framatone. The key transformation of CGN in this period of time was that it changed from an owner of nuclear power plants to an engineering company which would be able to perform engineering design. However, in a more realistic sense, the acquisition of this ability was achieved by a long term technology transfer through the Daya Bay and the Ling Ao Phase 1 projects. In this respect, CGN, in 2007 and 2008, was quite confident in claiming the maturity of the technology in its construction projects. In nuclear power industry, where maturity equals to reliability, CGN possessed, to some extent, a comparative advantage against CNNC and SNPTC. Even though the later purchased the right of use of the newest AP1000 technology from Westinghouse, the reliability of this new technology needed to be proved by real constructions.

From 2005 to 2010, CGN got 5 major projects throughout China, the Ling Ao Phase 2 project (2 units) in 2005 and accomplished in 2012, the Hongyan River project (4 units) in 2007, the Ningde project (4 units) in 2008, the Yangjiang project (6 units) in 2008, and the Fangcheng Port project (2 units) in 2010, with its CPR1000 technology. When Gen-3 technology became the main theme of the advancement of nuclear power technology, CGN was not left behind. In 2007, CGN entered into a contract with its old partner AREVA NP to construct the Taishan nuclear power plant with the EPR technology – Gen-3 technology by European standard. (Zhou et al., 2011) Associated with this contract, a technology transfer contract was signed through which CGN was granted a right of use of the EPR technology in China. It was intended by CGN that this new technology transfer contract would enable it to upgrade its own technology and educate a new generation of engineers especially designers.

The optimistic visions of nuclear power development would keep constant if the Fukushima accident had not happened in 2011. (Thomson, 2013) The tragic accident in Japan ignited a fierce debate on whether nuclear power plants should be built at inland sites in China. China's public media such as the central television station gave abundant reports on this accident and with the participation of some famous Chinese scientists such as Professor He Zuoxiu, the debate about the future development of Chinese nuclear power attracted the attention of the country's top leaders.

Almost immediately after the confirmation of this incident the central government ceased approval of new ATP[13]s to the constructions of nuclear power plants. Twenty months later, a new plan – China Nuclear Power Middle-Long-Term Development Plan 2011-2020 – was promulgated together with China Nuclear Safety Plan 2011-2020 on the 24th of October 2012. In this new plan, new nuclear

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[13] ATP: Authorize to Proceed

power plants shall only be built at coastal areas, previous attempts of launching nuclear power projects at inland areas are halted at least in the foreseeable future. In addition, as it was written in the safety plan, new constructs shall only adopt Gen-3 technologies which are considered to be safer in terms of a lower probability of design based severe accidents. (Thomson, 2013)

Even though there was no doubt that CGN participated in the drafting of both plans, the company's operation was still strongly influenced by the central government. First, CGN was forced to abandon its preparation for an inland project in Hubei province, and before that, the groundwork had already been started. The same situation also happened to CNNC's inland project. Second, the plans indicated a gloomy market future for CGN's CPR1000 technology because it was a typical Gen-2 technology. CGN responded to these changes promptly. On one hand, it started its self-reliant research and development to upgrade the CPR1000 technology to something that contained Gen-3 technical features. On the other hand, CGN started its pioneering attempts on the international nuclear power market because it was believed that not all countries would phase out nuclear power after the Fukushima accident and the domestic market would saturate when all the coastal sites had been taken. This international expansion intention was supported by the central government with the newly elected president and the premier promoting Chinese nuclear power technology and high speed rail system in their diplomatic visits.

In fact the second strategy of international expansion raised a demanding requirement for CGN which led to an emphasis on its self-reliant research and development capability. Over the years, CGN relied on technology transfer to acquire sufficient knowledge for its domestic nuclear power plant constructions. However, in order to become a qualified bidder for international nuclear power projects, an independent intellectual property right of the technology is required. Technology transfer contracts can only guarantee a right of use of the technologies in China under a license. That is to say neither the CPR1000 nor the EPR technology could support CGN's ambition of getting a complete international contract. This dilemma gave birth to CNNC and CGN's joint effort of making the real Chinese Gen-3 nuclear power technology with full property rights. But this was something that CGN had never experienced before. Therefore, it triggered a new round of reform inside CGN especially on its engineering design.

By the end of the year 2014, the future of nuclear power development in China and the business potentials of CGN became clear again. The basic design of the Chinese Gen-3 reactor HL1000 passed the safety review of the National Nuclear Safety Administration (NNSA). This led to a demonstration project granted to CGN on its Fangcheng Port site where the two CPR1000 units were still under construction. Another demonstration project was granted to CNNC on its Fuqing site where 4 Gen-2 nuclear power units has been built. Technically CGN's modifications to the already built CPR1000 units are accomplished by adding up some passive safety instruments to the active safety systems. This meant that the CPR1000 was transformed into a technology with some Gen-3 features, which gave CGN to build two more modified units on its Hongyan River site. All the good news arrived in early 2015, in the sense that the impact of the Fukushima accident might have fade away. However, the anti-nuclear power discourses over the inland projects are still persistent and neither CNNC nor CGN has received an approval on their inland construction plans by the central government. (CGN Website1, Accessed August 10, 2015)

In the international market, CGN signed a framework contract with EDF in order to ensure its participation in the EPR nuclear power plant construction in Britain. Independently, CGN was enlisted as the ultimate investor and the contractor of a nuclear power plant project in Romania. On top of all these business successes in 2014, the most significant commercial success for CGN was that CGN became a listed company on the Hong Kong stock market on December 10th 2014. This means that CGN is now having greater financial power to support its future expansions both domestically and internationally than ever before. (CGN Website1, Accessed August 9, 2015)

Through this commercial storyline of CGN’s development, it is hard to measure in technology innovation terms, how much progress has been achieved by this company which changed from a small joint venture with only several hundred employees to a nuclear power group company that employed more than 10 thousand engineers and other professionals. What seems to be evident is that along with CGN’s commercial expansions, its scope of engineering extends as well. CGN learned the technical know-whats of a nuclear power plant in the Daya Bay years, and gradually learned nuclear power plant project management section by section – procurement, site management, and system testing – in its cooperation with AREVA NP and EDF. Under the technology transfer contracts, CGN engineers learned the technical know-hows – engineering designs – of how to build a nuclear power plant, and finally, under market pressures traced back to some technical know-whys on nuclear power related scientific knowledge which could be immediately used on its research and development activities.

In short, CGN’s acquisition of scientific and technological knowledge is not strictly in line with the trajectory which starts from research and development activities. It is much similar to a reverse track. Its expansions have been closely related to the political climate shifts in China over the years after the opening-up and the economic reform. Social concern about nuclear power technology has never been a dominant factor to define the fate of nuclear power in China. The commercialization of science and technology, according to me, serves as the most important momentum of its triumph in the market. Even though, it is indicated in this chapter that engineering design emerged and evolved in CGN along with its implementation of different projects, the questions of how CGN engineers learn to practice engineering design are still unclear in this one dimensional – commercial – interpretation. Such questions will be dealt with in the following sections of this chapter, but at this point, I would rather conclude the growth of CGN a commercial innovation.

3.2. TYPES OF ENGINEERING DESIGNS IN CGN

From CGN's engineering practices, engineering design is treated as one phase of the engineering process in its project implementation. This perception of engineering design leads to two different understanding of its functions. First, engineering design can be used as a tool to provide verifications of the business actions of the investor for example the procurement activities. Second, engineering design itself can be regarded as a form of decision making to regulate the follow-up engineering activities such as manufacturing and installation of equipment and the construction of buildings. Each of them implies different knowledge or information requirements. In this respect, it indicates that in different periods of CGN's history, different types of engineering design might have existed depending on the work that CGN engineers performed.

In the standard FIDC[14] contract definitions of the owner and the contractor or the supplier, their scope of work can be portrayed as the following:

> The Employer or the Owner: He shall grant access to the Site and possession of the site, make arrangements for payments, pay the Contract Price, disclose site data and co-operate with the Contractor to the extent provided by the Contract. He shall also compensate the Contractor for additional cost and disruption if a risk eventuates which is borne by the Employer. (Jaeger and Hok, 2010, p. 177)
>
> The Contractor: The Contractor promises to the Employer to complete the Work and to remedy any defects therein. If the contract provides for the design by the Contractor, then he will design the Work as well. The design, if any, and the completion of the Work including the remedying of defects shall be accomplished within time for completion. Moreover,

[14] The International Federation of Consulting Engineers (commonly known as FIDIC, acronym for its French name Fédération Internationale Des Ingénieurs-Conseils) is an international standards organization for the construction industry, best known for the FIDIC family of contract templates. FIDIC was initially founded in the French speaking European countries and regions and gradually got accredited in continental Europe, (Jaeger and Hok, 2010)

> if the contract provides for the operation of the Work by the Contractor, then he will operate the Work. (Jaeger and Hok, 2010, p. 191)

According to the definitions, knowledge or technology is not the ultimate commodity pursued by the owner of a nuclear power plant, but electricity is something that can be sold on the market. Therefore, it is what the owner wants. However, in order to generate the commodity, technology of building such an infrastructure facility is needed. The question is whether the owner is necessary to possess that sort of engineering ability in the long run or such expertise can be temporarily hired in the market. Even though engineering design is not necessarily the work of the contractor, due to economic concerns, the owner might not want to acquire the same technical abilities as the contractor. As a result, engineering design may be allocated in both the owner and the contractor's scope of work, its contents may vary. Such differences derives from the different problems confronted by the owner and the contractor and can be manifested by the different approaches of problem-solving.

In the nuclear power industry, especially in China, the owner takes the responsibility of nuclear safety, that is to say it needs to go through a licensing process to get its permission of nuclear power plant construction and operation. The theme of this licensing process is an evaluation of the design which describes the technical safety features of a nuclear power plant. The owner answers questions raised by the NNSA under a promise of the contractor who knows more detailed knowledge than the owner in the sense that the contractor knows how to accomplish its promises but the owner only requires a result. A result will be sufficient to help the owner to get its license and in this respect, a review of the contractor's design will be enough. In CGN's engineering practices, especially in the Daya Bay and Ling Ao Phase 1 project such design reviews served as the major engineering design activities when CGN acted as the owner.

In CGN, even today, economic feasibility studies of any new built nuclear power plants are regarded as a part of engineering design. In these studies a business model is built with the basic data from equipment manufacturing, the labor market and the electricity market. The model has two functions. On one hand, it could be used to present to the government's economic regulatory bodies that such an investment is feasible. On the other hand, such a model can be used for the owner to deal with its financial matters such as the variations of the contract with the contractor. But in any case, technical contents in these studies are very general.

It doesn't mean that engineers in an owner company do not have to know much knowledge about the nuclear power plant, but it just seems that knowing some basics will be enough to fulfill his or her daily tasks. Perhaps the most important skill for them is to understand the plant's basic design. In case of profound or detailed questions, the owner can easily purchase relevant expertise in the market from a third party when independent assessment is needed. Hiring EDF for technical assistance in the Ling Ao Phase 1 project was an example of this approach of engineering problem-solving, from a commercial perspective.

Unlike the owner, the contractors – such as AREVA NP and Westinghouse – appreciate technology, knowledge, or their design engineers as the most valuable resource. They have to maintain a persistent capability of duplicating the construction experience of one nuclear power plant to another site, another country or another culture. At the same time, in order to adapt to new technologies, such as the adoption of ICT technologies in plant control, some research and development is also needed. Normally, these research and development activities are called modifications or improvements on the already established engineering models. In this respect, technical innovations in nuclear power projects are achieved in a gradual manner. When new technology emerged, such as the digital control system, it is the design engineers in these companies to transplant it into the nuclear power plant system. In order to accomplish this transplantation, sufficient technical know-hows with scientific know-whys are needed, because the intrinsic safety of a nuclear power plant design is based on a confidence of a thorough understanding of the object to be added in the system. As a result, from the technological knowledge making point of view, the real engineering design is performed by the contractors because knowledge is the commodity that can be sold to the owner.

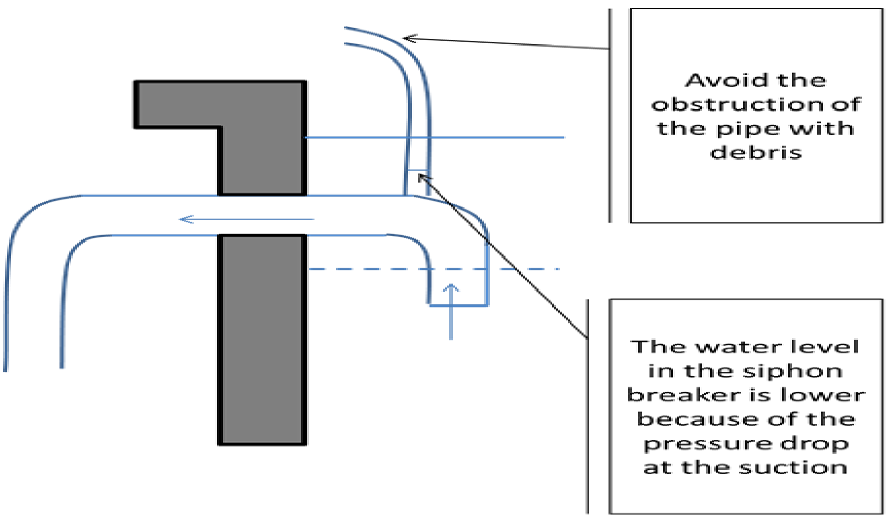
CGN's engineering design, in a realistic sense, started in the Ling Ao Phase 2 project. From an organizational perspective, CNPEC the newly established legal person was detached from the owner company. In this respect, CNPEC was pushed to act like a contractor even though people may question the foundation of its knowledge reserves, especially to compare this newbie to the veterans such as AREVA NP or even CNNC. Largely, the engineering design in the Ling Ao Phase 2 project was an authorized duplication of the technical drawings used in the Daya Bay and the Ling Ao Phase 1 projects with their later technical modifications. Due to this duplicative feature, even though the project was accomplished in 2012 with more than 80% of the major equipment manufactured in China under CGN's design, and the entire plant's buildings were designed and constructed by Chinese engineers and workers, it was still not convincing enough to say that CGN – CNPEC specifically – had tapped into the details deep enough for this nuclear power plant's engineering design. (CNPEC, 2013) That is to say, that CNPEC might has been put on a position as a contractor but it still takes time for CNPEC engineers to learn the essence of engineering design through their later practices.

One example to illustrate this process of transformation from the owner typed design to the contractor typed design is obtained from my own observation. As the project manager of the EPR technology transfer contract, I am given some opportunities to witness the training courses of AREVA experts to CGN design engineers as a part of the technology transfer contract's quality control. The following story is what I saw in March 2015.

The course was about the design of a safety system (PTR system) related to the spent fuel pool – a water tank to remove the decay heat of the fuel assemblies stored in the spent fuel during normal and accidental conditions. The basic requirement of the design of the PTR system is to keep the water level inside the pool relatively stable so that it will never cause an internal flooding inside the nuclear island that will impair other devices and the water level shall never drop too low because even the partial uncovering of the spent fuel assemblies will cause radioactive release which is in fact a nuclear accident. Therefore, it is not difficult to imagine that this system consists of pipes, pumps, valves, detectors and digital control devices. One major task of its design is to find out how many and what types of pipes and pumps are needed both to discharge water into the pool in case the water level is too low and to suck water out of the pool in case the water level is too high.

In order to make sure that this system is completely safe, the designers shall take into their considerations the situation that the pipes may crack or break for whatever reasons. In that case passive drainage risk (siphoning) may occur which is induced by the break on the pipe or in other places on the circuit connected to the pool. If that happened in the suction operation of the system, the water level drop would be uncontrollable, in the sense that the water level will drop to the lowest end of the pipe, as it is shown in the following drawing. In order to prevent this situation, a siphon breaker is needed so that in the case of a break, the water level would only drop to the position where the pipe is inserted – shown by the dotted line.

Figure 3-1 A Design of the Siphon Breaker



With some basic knowledge of physics CGN designers certainly understand the reason why a siphon breaker is put on the main pipe but in real life engineering design their tasks remain uncompleted at this level of logical reasoning. They have to identify the diameter of this siphon breaker which is in fact a small pipe as it is shown in the drawing situated on top of the main larger pipe. In addition to that, they have also to consider the specifications related to the welding of this siphon breaker to the main pipe. Needless to say, how long it shall stand on top of the water level and the angles of the curve at its top end should also be determined. All these details should be clearly identified so that the manufacturer or installation workers on site will follow, otherwise, those who implement the design will not know what to do. These specifications are the knowledge produced in the detailed design.

Previously, in the Daya Bay and the Ling Ao Phase 1 project, understanding the principles of design such as the recognition of a siphon breaker on the drawing would fulfill the requirement of a design review task. Because, the owner of the plant only needs to know the completeness of the system, but as somebody who directs the installation and manufacturing, information as the diameter, the length, and the shape seems to be important because the workers need to visualize what is supposed to be made. In this respect, the major difference between the owner typed engineering design and the contractor type appeared at the level of detailed specifications. From the Ling Ao Phase 2 engineering design, these details need to be worked out by CGN designers. This led to one of CGN trainee's questions to the trainer from AREVA NP – how to define the specifications of this siphon breaker?

The answer given by the AREVA trainer was a surprise to CGN designers because he said that he did not work out the specifications. Later he pointed out that it was the pipe manufacturer who completed the detailed design based on their design manuals in the factory, but in the AREVA tower there was no such manuals and importantly he was not required to make a detailed drawing at that level. CGN designers' remark to his answer was that in their designs of the CPR1000 units such detailed information was needed, and it was what they found strange in AREVA's technical files received from the technology transfer contract that no such information was included. CGN engineers worked out this problem by their own calculations. Even though it was not a difficult problem to solve, they did hope a handy design manual existed so that they would not spend that time for this tiny problem on one hand, and would have some references of the correctness of their designs on the other hand. Then a request for transferring this design manual was raised by one of the trainees but it was rejected from the trainer because he was certain that this information belonged to the intellectual property right of AREVA's sub-supplier. Therefore it should be out of the scope of the technology transfer between AREVA NP and CGN.

After this short discussion, a more interesting question was raised about how to choose the material – the stainless steel – used on this siphon breaker. The trainer claimed that it should be the same as the main pipe which should have been tested to work properly under such conditions – radioactive and under water. He was certain that studying the physical properties of metal materials was not his scope of work, if CGN engineers were interested in these topics, they might need to trace back to the research and development documents of the piping manufactures. The trainer understood that the trainees might think about possible improvements, such as prolonging the duration of this small piece of equipment but he really did not know that much. Perhaps all of them in the classroom realized that such a profound question which seemed to be important and interesting was not a proper question in engineering design. However, it could be a proper question in terms of research and development. None of them kept a focus on that question, but at the same time none of them would admit that such a question was not relevant. In this respect, the demarcation of design and R&D seems to be quite blurry.

This example can be used to explain many aspects of CGN's engineering design practices, not just some comments on the technology transfer, even though it illustrates why CGN engineers always think that the technology transfer between AREVA NP and CGN is not sufficient or complete enough. According to this story, one reason for this feeling as if AREVA has been hiding something, is that some engineering design tasks in CGN are ascribed to manufacturing activities as they are defined in AREVA NP. There might be some cultural reasons for this difference of habits but in general, I tend to think that technology transfer is not purely technical. As I can summarize from the implementation of the contracts, technology transfer resembles a communication process in which experience is transplanted from one organization to another.

Relating this small case to the entire engineering design of a nuclear power plant, the meaning of Paul and Beitz's systematic design approach and its well-recognized phased design procedures becomes clear in this engineering company. According to Paul and Beitz conceptual design refers to an array of human mind activities, namely, abstracting to find the essential problems, establishing function structures, searching for working principles, combining working principles into working structures, selecting a suitable working structure and firming it up into a principle solution – a concept. (Paul and Beitz, 2007) In CGN's engineering design practices, conceptual design refers to the clarification of the major technical specifications and functional requirements of a nuclear power plant. These specifications and functional requirements include nuclear power plant's capacity, general layout, safety parameters, life span, etc. such as the technical descriptions of the HL1000 nuclear power plant [15]on CGN's official website.

These specifications serve as common goals of the owner of a nuclear power plant and its construction contractors. They are also guarantees – on a hypothetical basis – of ensuring nuclear safety. Together, these hypothesis and the limits shaped the technology that distinguish a typical type of nuclear power plant to another. With the data and brief illustrations, it is difficult to imagine what the nuclear power plant will be looked like even for the nuclear power professionals. It is also extremely difficult for the general public to set up a correlation between the concepts and nuclear safety. But they are sufficient to construct a set of criterions by which the quality of engineers' work can be measured.

Making the concepts visible on paper or computer screens is the work of engineering designers who perform the basic design or embodiment design. In CGN these engineers are called system designers. In this phase, designers start from the selected concepts to produce a definitive layout of the proposed technical product or system in accordance with some technical and economic standards or limitations. The result of CGN's basic design for a nuclear power plant can be demonstrated by the following graphics.

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[15] HL1000 Technical Specifications:
- Reactor core with 177 advanced fuel assemblies (STEP-12)
- Three trains (100%) of physically separated engineered safeguard systems
- Single reactor layout
- Molten corium in-vessel retention (IVR) - passive reactor pit injection system
- Secondary side passive residual heat removal system
- Core damage frequency < 1×10-6 /reactor year
- Large release frequency < 1×10-7 /reactor year
- Core thermal safety margin > 15%
- Design basis seismic class up to 0.3g
- Double containment capable of withstanding the impact of a large commercial airplane
- Comprehensive severe accident prevention and mitigation measures
- FirmSys, a proprietary nuclear-classed DCS system platform
- Leak-before-break technology
- Radioactive waste management system meeting waste minimization requirements
- Eliminating the possibility of large radioactive release in design
- 60 years of design life
- Plant availability up to 90%
- Localization ratio: 85% for-rst unit, 95 % for mass construction

(CGN Website2, Accessed, April 13, 2015)

Figure 3-2 HL1000 General Layout

Figure 3-2 is the general layout of a HL1000 power plant. The major function of this graphic is to express a visionary model of a nuclear power plant at its completion. In this computerized graphic, it is much easier to identify where the nuclear island locates and where the turbine generation is supposed to be installed. In this respect, it is a demarcation of the physical units of the entire system by graphical expression. Together with Figure 3-3 listed below the complete flow of a controlled nuclear fission reaction for the purpose of electricity production can be demonstrated.

Figure 3-3 HL1000 nuclear power plant's profile model

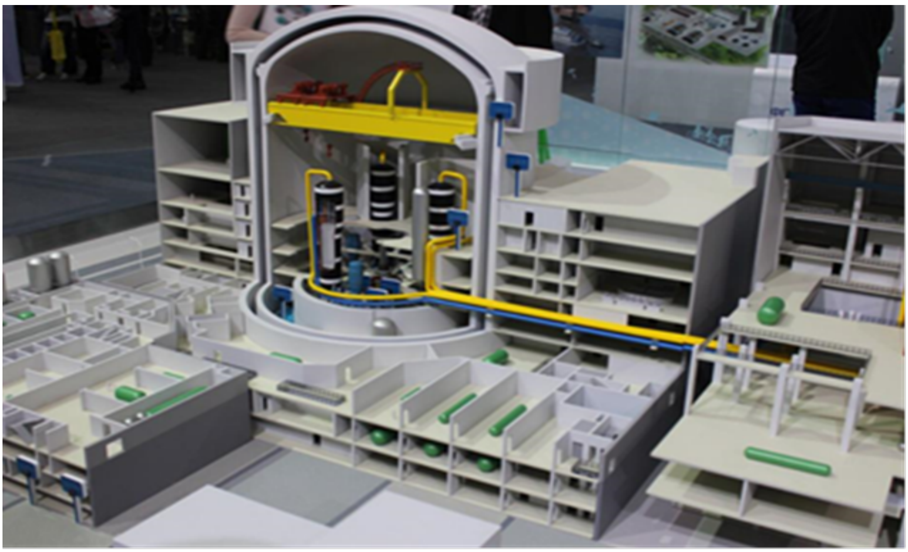


Figure 3-3 is a 3D demonstration of the water and steam circulation of a HL1000 nuclear power plant, with the blue pipe representing water and the yellow pipe representing steam flow. Equipment and the main internal structure of the building are expressed in this model. Such a model is largely used to express the completeness of the nuclear power system. Even though digital control logics are not expressed in this model, with some engineering knowledge such logics are not difficult to be represented in the minds of those specialized engineers.

Model building is the essence of nuclear power plant's basic design. With this model, the contractor will be able to provide a more convincing guarantee to the investor the foreseeable success of its construction. The investor will use this to model to conceive its project management and deal with its licensing process.

However, at this stage the connections between engineering design and its subsequent equipment manufacturing and building construction activities are still not completely apparent. For example, the sizing of equipment is not determined, and the methods of building constructions are not defined. All these details are left to the detailed design of the nuclear power plant, and in CGN, they are the tasks of the equipment designers and civil work designers. These detailed designers have to foresee what is going to happen in the manufacturing factories and on the construction sites, so that their graphics and documents can be realized into different types of machines, be it a tank or a heat exchanger, or different types of building structures be it a concrete dome, or a steel structure. The example of the design for a siphon breaker given above is an illustration of the knowledge used in the detailed design.

Paul and Beitz's (2007) engineering design methodology derived from their observation of machine making activities. In some respects, they did not distinguish R&D activities from normal engineering design activities such as the designs based on duplications of already established models. In their book, a typical sequence of engineering design starts from the generation of concepts and ends with the furnishing of details. Regarding to CGN, it might be proper to say that this company spent about 30 years to establish this complete chain of engineering design.

At the beginning, with the aid of a technology transfer contract, the conceptual and basic designs for the Daya Bay and the Ling Ao Phase 1 project were just a review of the French M310 units' designs. Taking into the consideration of the contents of knowledge – details of information – such duplications were sufficient for CGN's to act like an owner. However, when CGN transformed from an owner to a contractor, detailed design seems to be the missing chapter in the technology transfer. Therefore, CGN has to rely on its own engineers to fill this knowledge gap.

CGN learns to perform nuclear power plant engineering design from different types of projects and it is due to the different roles that CGN has played in these projects that the company shaped its own understanding of engineering design. This understanding, from a knowledge making point of view derived from the different topics of questions emerged in the projects. The following chart may illustrate this transformation.

Table 3-1 Differences between CGN as the owner and the contractor

Topics of Questions	CGN as an Owner	CGN as a Contractor
• Contractual obligations	• How to issue bidding documents? • How to get construction permissions?	• How to respond to the owner's requirements? • How to work with manufacturers and construction workers?
• Limitations and restrictions	• Laws and governmental regulations	• Technical standards and codes
• Problem-solving approaches	• Technical problems can be broken down and solutions can be found in the market	• Functions can be achieved by proper physical structures
• Verification of solutions	• Independent third party can be hired to ensure fairness and impartiality	• System functions can be verified by tests • Quality can be justified by quality control and quality assurance systems

In this thesis, I tend to regard Paul and Beitz's three-phased engineering design as a widely accepted description of engineering design in the sense that such engineering activities as reviewing the basic design performed by AREVA NP, the duplication of drawings and perhaps the translation of documents can be counted as engineering design activities, because each of them can be traced, more or less, in Paul and Beitz's descriptions about the real life design process. In addition, these activities are also performed by engineers in AREVA where the systematic design approach is adopted.

What I indicate in this chapter is that these types of designs all exist in CGN depending on the role CGN plays in the project. Perhaps this co-existence is both an advantage and a disadvantage for engineers working in such an organization.

3.3. A CULTURAL INTERPRETATION OF CGN'S ENGINEERING DESIGN SYSTEM

In the last a few pages of Engineering Design - A Systematic Approach the Third Edition, the editors of the book presented some positive comments about the adoption of this design approach in industry. They wrote:

> Industrial companies applying a systematic approach state:
> • The number of patents, in particular defensive patents, has increased.
> • The overall duration of development projects is shorter, despite longer conceptual design phases.
> • The probability of finding good solutions is greater.
> • It is easier to manage the increasing complexity of problems and products.
> • Creativity increases while maintaining realistic deadlines.
> • A transfer effect is noticeable, that is, staff work more systematically in other areas.
> The following side effects are observed:
> • information flow improves
> • teamwork and motivation benefit
> • communication with clients increases
> (Paul and Beitz, 2007, p. 583)

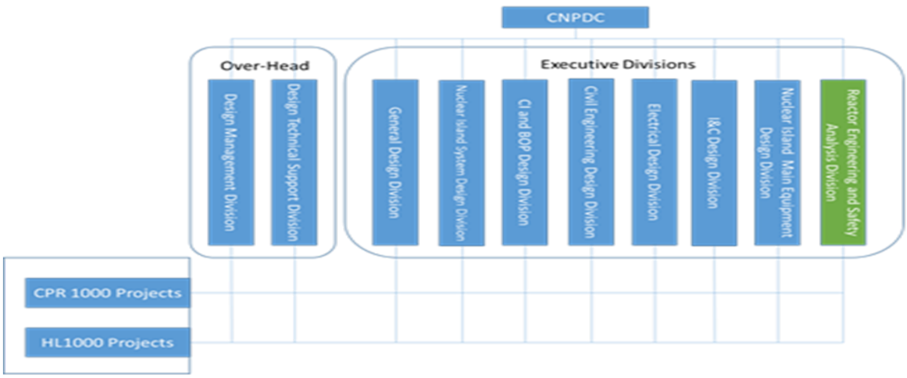
These positive comments on the systematic approach reflect a good compatibility of this approach with industrial production. As it is written, this approach enhances efficiency of problem-solving inside a company and its side effects help engineers to meet clients' demands. In addition to the scientific reasons for these results, I tend to think that such compatibility derives from some cultural reasons.

Regarding to CGN, the most evident advantage of the systematic design approach is that it complies with the scientific thinking which permeates in engineering practices. First, the approach is constructed on the presumption that difficult problems can be broken down to less complicated tasks. The second presumption is that sufficient answers to engineering problems refer to detailed information. The combination of these presumptions leads to a conclusion that no matter how difficult a problem – a hypothesis or a tentative answer – is, it can be realized by a systematic broken down of the problem into smaller problems and its sufficient answers can be achieved by finding out enough relevant details. It seems to me that these engineering habits are nurtured both in engineering education and in professional practices. Therefore, when AREVA introduced this approach to CGN, our engineers accepted it without substantial difficulties because they found such a theoretical framework highly relevant to their life experiences.

Another reason for the preference over the systematic approach of engineering design in this company is the hubris reflected by CGN's engineers' attitude in the sense that with this approach which predicts a solution to any problem, engineers gain confidence of a project's completion to avoid a sense of frustration at the beginning of their work. That is to say, at the beginning of a project, engineers tend to believe that their work will succeed in the end. From the commercial perspective, such a confidence caters to the demands of the investors. In this respect, it explains why engineers always emphasize that their engineering goals and solutions are practical – achievable – at least in CGN.

CGN's engineering design organization – in terms of its structure – is highly influenced by this mindset. Together with the theoretical guidelines provided by Paul and Beitz, it can be clearly identified that the division of labor in CGN's engineering design institute (CNPDC) takes both the sequential and disciplinary features into consideration. The chart representing CNPDC's organizational structure can be illustrated as the following:

Figure 3-4 CNPDC's organizational structure



The general design division in CNPDC takes the responsibility of the conceptual design for a nuclear power plant. The engineers in this division serve as consultants to the owner. They perform economic feasibility studies, issue operational regulations, and most importantly gather information from already built nuclear power plants to create new concepts of CGN's future plants.

The basic design of CGN's nuclear power plants is done in the system design division. As it has been illustrated in the previous section, concepts are transformed into flow charts and engineering models through calculations and graphical demonstrations.

The civil work, main equipment, digital control, and even the conventional island – mainly the turbine generator – design divisions are considered as the detailed design divisions in CNPDC. Each of them focuses on pieces of equipment, or single buildings. They build the system out of proper physical structures.

The reactor engineering and safety analysis design division seems to be different from all other divisions. The reactor pressure vessel's mechanical design is performed by the main equipment design division but in such a detailed design the designers might not question the scientific know-whys related to nuclear safety. For the mechanical designers, the reactor is just a pressurized vessel, and what they do is to make the vessel sturdy and durable. What makes the nuclear power mechanical engineers different from their peers in other industries is that they have to consider the making of a machine in a highly radioactive environment. The physical and chemical reactions inside this vessel are out of the concern of the mechanical design engineers. It is the task of the reactor engineering designers to work out mathematical models of these reactions. With these models the reactor engineering designers will be able to justify the intrinsic safety of the entire nuclear power plant. Therefore, the products of this reactor engineering and safety analysis design division consist of computer codes in which the scientific language of nuclear physics is translated into engineering languages, and some verbal illustrations – the safety analysis reports. The preliminary safety analysis report (PSAR) will be used for the application of construction license by the owner, and the final safety analysis report (FSAR) will be used for the application of the license of operation. In this respect, this design division provides scientific verifications to the other engineering disciplines in CNPDC. Perhaps it is due to the scientific nature of its tasks, this engineering design division is shared both by CNPDC and CNPRI – CGN's R&D subsidiary.

With this organization structure, the information flow inside CNPDC is not difficult to be deduced. The general design division provides the initial input, and then the system designers translate the general technical functions and economic requirements into achievable smaller disciplinary goals. What followed this system construction phase is some parallel similar sub-system construction work until enough information or knowledge is produced to the details of each piece of equipment and each level and unit of the buildings.

The so-called interfaces of engineering design derive from the division of labor within this design organization. In this respect, two types of interfaces exist in CGN. From a top-down perspective, there exists a necessity to set up a mechanism of information exchange between different phases of engineering design, such as the passing down of the conceptual design results to the basic design and the information exchange between the system designers and detailed designers. From a horizontal perspective, information exchange also exists among different engineering disciplines, such as the equipment designer with the civil work designer, the electronic designer with the digital control designer. The bottom-up mode of information exchange is also common in CGN's engineering designs especially when discrepancies appear in site construction and manufacturing activities. Often these discrepancies lead to the modifications or variations of engineering design, but it is understandable that the greater the scale of modifications need to be done the greater the difficulty they will pass up to the upper level. For example, a change in a pump will not lead to the change of the basic design and not to say the conceptual design. In fact, the conceptual design may never change once it has been decided by a group of experts.

From the information exchange perspective, engineering design management in CGN can be regarded as a control of information, both its flows and its timeliness. Sufficiency of information is often a topic of concern among different engineering disciplines – the interfaces. In order to resolve these tensions, CGN forms an engineering design management division in CNPDC. This design management division consists of several project management offices each hires some coordinators. Unlike the design engineers who might participate in several nuclear power plant projects, the coordinators are positioned in one particular project. They monitor the progress of design, and they channel information exchanges between the divisions in one project. Another function of the design management project office is that it serves as the interface between engineering design and the other engineering activities included in the construction process such as procurement and installation.

In order to pin-point a design engineer's function or position in CGN's engineering design system two indicators are needed, with one delineates his or her disciplinary feature, and the other points out his or her project attachment – e.g. Mr. X is the system designer for CGN's Taishan Project. It might be proper to pose a cultural image on CGN's engineering designers as information processing machines, because on one hand, their daily work can be regarded as receiving inputs and producing outputs, on the other hand they also have to transfer information to their upper-level engineers when they find a problem that they cannot solve, and to their peers when they are certain that the problem is out of the scope of their responsibilities.

Two series of management on every single designer are evident. The division decides which project they are appointed to, specifically on the issues like whether they should be dispatched on-site, and their promotions to a higher professional hierarchy which normally indicates their competencies of solving complicated problems. The higher the ranking an engineer reaches, the greater the power he or she might possess in technical decision making and also the more junior engineers working under his or her supervision. The project line of management evaluates the results of their work and translates these assessments into economic terms. Financial rewards will be given to those who accomplish their tasks in a timely manner with accepted quality. That is to say the more projects a designer participates in, the higher income the designer may expect. The principles of scientific management are realized in CGN as such. That is the reason why in the previous chapters of this thesis, I categorize the systematic design as a scientific approach of managing engineering design which is indicated by the economic meaning of engineering. In this respect, the systematic design in CGN is based on an analogy of knowledge production to the mass production of goods.

In fact, the power distribution in CGN's engineering design system is not balanced. It is quite obvious that the division's – administrative – power is more influential than the project's. This uneven distribution of power might derive from the Chinese traditional habits of attaching science and technology to power. But taking some economic concerns into consideration, such a structure seems to be understandable because projects have their lifecycles. Therefore they cannot guarantee a lifelong employment of any engineers. Since a lifelong employment is certainly more appreciated, engineers are more willingly to follow the instructions of the division instead of the short-term project. This is a reason why cross disciplinary job-hopping is so rare in CGN, and perhaps it increases the difficulties in cross-disciplinary problem-solving. It also indicates a comparative advantage of some seemingly important divisions such as the system design division and the reactor engineering division because engineers in these divisions are closer to the critical and comprehensive knowledge of a nuclear power plant while others seem to have less opportunity to get access to that knowledge. In such a circumstance, in order to have a relatively better career development, mechanical engineers, electronic engineers, and others choose to become more specialized in their already narrowed disciplines.

3.4. SOME IMPLICATIONS

Through the history of CGN, I illustrate how Chinese traditions influence the shaping of CGN's engineering designs but it seems to me, that such influences are more obviously reflected by the organization in terms of its management styles. Direct links of the culture to the individual engineers are not as evident as they are exemplified by the organization. From my observation, CGN is developing in a relatively isolated arena in society where the outside seems irrelevant to CGN's engineers. If it is the case, are Paul and Beitz wrong? They indicate that at least in the conceptual design of a technical artifact, communications between engineers and their clients are quite necessary. Regarding to nuclear power engineering in China, especially to CGN, the conceptual design seems to have other origins. One origin may be the habit of learning from West; the other seems to be CGN's ambition – its own intention. No matter what the origin is, it is not originated from CGN engineers' communication with the society in a broader sense.

If the communications of engineers with the society do not exist in CGN, how can I study the dynamics of engineers with the culture? At this point, I need to insert another presumption that such communications exist but they are distorted. This distortion can be explained by the following aspects.

One possible explanation of the distortion is that CGN engineers hold a separated view of nuclear power, regarding it purely as a technology. Therefore, the generation of concepts in engineering design derives from a pursuit of technological improvements. Efficiency becomes the keyword. Such a tendency can also be found in the minor modifications in the detailed designs. That is to say, CGN engineers tend to develop their ideal nuclear power plant which they consider to be advanced. As a consequence, technological advancements are translated as better solutions to the problems appeared in the society. In this respect, engineer's communication with the society, in CGN engineers' interpretations, equals to a public understanding of their advanced inventions.

From a commercial perspective, like many novel technological products such as the new mobile phone, nuclear power plant also requires market promotions. However, compared to those products, the advertisement of nuclear power is achieved by a persuasion of the general public to accept this technology by assuring its intrinsic safety in high-tech exhibitions or by carrying out public opinion surveys instead of investing a lot of money on TV or Internet commercials. In this respect, the aim of such advertisement is to educate normal people that the risk of radioactive release can be effectively controlled. The reverse direction in the communication – learning from the people – is considered as unnecessary or troublesome.

Considering the fact that in China, the ultimate client of nuclear power plants is the government, such distorted public communication is utilized as evidences of public acceptance which can be submitted to the authorities in the licensing process of a nuclear power plant's construction and operation. When scientific decision making becomes the standard procedure for industrial development plans, CGN's public communication is rendered in a social science fashion.

Studying the relationship between nuclear power and the society with the social science paradigm has two advantages for CGN. On one hand, numerical expressions seem to be more convincing and understandable for CGN engineers to know the images of nuclear power and perhaps its social status in the society. On the other hand, since engineers are quite familiar with the manipulation of data, social science can be appropriated as means to channel public opinions. At least, it will be more effective to get governmental permissions on certain development plans with scientific reports which show facts in numbers.

Such an appropriation of social science for the purpose of business interests is adopted by CGN. However, it seems to me that the utilization of the surveying methods has not been professional enough. In November 2014, a survey and a videotaped interview with university students were carried out by CGN's public relation department in Guangzhou – the capital city of Guangdong Province where higher education institutions are concentrated.

In this survey, interviewees were first asked about their images on a nuclear power plant by an analogy of this technical artifact to an animal.

Figure 3-5 Screenshot of the videotaped interview by CGN

In this screenshot the respondent replied that the nuclear power plant was something like a lion which represented both strength and danger to human. Other replies of this question included crocodile, tiger, horse, dog, and dinosaur. To some extent, the answers from the university students reflected diversified cultural images on nuclear power in China. They indicated both positive and negative comments of this technology among Chinese university students. Through these answers, some traces of the Chinese traditional assessments of science and technology, such as its threats to human life, can be revealed.

In the questionnaire survey, some carefully designed questions were asked. For example one question asked: "if nuclear power developments are based on sufficient public communications, such as public participation in operation monitoring and environmental impact consultation, will you accept the application of this technology in more locations in China?" The result was that more than 70% of the interviewees provided positive answers.

With this figure is it sufficient to reach to the conclusion that the majority of the Chinese people, at least the well-educated people, support the development of nuclear power? I am doubtful to that definitive conclusion. My confusions derive from some of my interpretations of the background information gathered in this survey with its final results and claims.

First, more than 70% of the interviewees' hometowns are currently nuclear power free and there is no nuclear power development plans announced or no plant has been built in the places from where they come from. Is it to say that at the time of the survey, nuclear power was an irrelevant topic for those respondents?

Second, along with the survey, a simple test of the basic scientific knowledge of this technology was carried out to both the science and technology streamed students and liberal arts streamed students. The result showed that more than 60% of the attendants scored lower than 6 out of the full score of 10. This result in the Chinese educational grading system equals to failure. With this result, CGN concluded that a lack of scientific understandings to nuclear power technology was evident among Chinese university students in general. "Lacking scientific knowledge" is often the comment that some nuclear power experts give to the sociologists and humanists who oppose this technology. In this survey, the irony was that CGN wanted to use the finding that 70% of the university students supported nuclear power development to legitimate its business ambitions but evidences showed that these respondents were also scientifically not qualified.

CGN realized this irony. Therefore, the report of this research was written with a title saying that 70% percent of the Chinese university students support nuclear power development. However, looking into its content, it can be found that the conclusion has been made to claim to the government that the popularization of nuclear power related scientific knowledge is important. The reason for this inconsistency of the title and its conclusion, as I can explain, is that the intention of the title is to strengthen a confidence in CGN engineers who devote their careers to the development to this controversial technology. While the conclusion as it was written in the report might be the only way to get CGN out of this irony. Because, as a company whose survival depends on scientific disciplines which indicate honesty as a part of its social responsibilities, it cannot fabricate data. Otherwise, it is highly likely that its public image will be destroyed. The only thing that CGN can do is perhaps to hope for some new data. For that purpose, CGN needs to put some effort in changing the society from which the data generates. Needless to say, it is not easy.

Something that I have learned from this case is that social scientists have been employed to serve for commercial interests in this company. In order to comply with the system, or to get acknowledgement from the engineering colleagues, social scientists have to act like engineers. However, the object of their studies or perhaps designs is different from that of engineers. This difference leads to the irony that has emerged. Perhaps the most challenging job for the social scientists in this company is to eliminate this irony.

CHAPTER 4. ATTEMPTS OF IMPROVING ENGINEERING DESIGN INSIDE THE SYSTEM

4.1. A PARTICIPANT OBSERVATION

It is not the theme of this PhD thesis to study the topic of improving engineering design from a perspective of technological innovations. As far as I am concerned, technology innovation serves as one end of improving engineering design, but it is certainly not the only goal that improving engineering design shall be base on. From a retrospective, the quantitative methods mentioned in this chapter is not the research methodology applied in my PhD research. In this respect, it seems not necessary to present the results of both the company and the self-motivated research activities in details. But this experience has a lot of meanings. On one hand, it shows to the reader how a company policy research is performed in CGN and how the habits, tacit norms and rules, and the organizational culture shape the fashion of this kind of researches. On the other hand, it depicts CGN engineers' understandings and approaches of how to improve their work. Thirdly, it is quite evidently reflected from this experience what kind of changes the company wants to bring about.

It is shown in this chapter that finding what needs to be improved is a social process. The interpretation about the research findings is also a social process. Perhaps, all these activities can be regarded as attempts to change the organizational culture. What seems to be convincing is that changing the culture is not easy in this organization because in a company where uniformity overwhelms diversity, conflicts of opinions are often resolved by compromise. My participant observation reveals the resolution of these conflicts and it is a supplement to my main research for this PhD project.

4.2. FROM A SELF-MOTIVATED RESEARCH TO A COMPANY PROJECT

In 2013, a few months after the initial literature study, I carried out a questionnaire survey and some interviews with CGN engineers and managers to get some general understanding of how they think about improving engineering design. At that time, these research activities were completely self-motivated with an intention of using these researches as the preliminary research of this PhD study. The choice of the quantitative research methodology for an understanding of what are the constituting elements of engineering design capacity – Multidimensional Scaling (MDS)[16]– derived from my feeling that even though I was working for the Taishan project, I still found my contacts with our design engineers limited. Due to the over-specialized division of labor in CGN, and the geographical separations of the offices among different departments, it was very difficult for me to get access to the general perception of engineering design in a short period of time. In addition, I found it not convincing to build my entire research about this technical question[17] on some limited number of qualitative interviews. As an engineering student, I tended to use questionnaire surveys to cope with all these difficulties.

Another part of the self-motivated study was an evaluation of the identified approaches of improving engineering design by a binomial test[18] which Christopher Freeman (1974) used to evaluate successful technical innovations in the 1970s. The basic presumption of the choice of this methodology was to avoid personal prejudice, such as some engineers thought that receiving technical training was a waste of time in their personal improvements of their design skills while others considered it to be vitally important. Statistics might be a tool that I could use to eliminate personal preferences.

Some major records, calculations and results of these researches are attached in the Appendix A of this thesis. As a summary, I tried to carry out a quantitative research with an intention to manifest the relationship between some personal features and the result of engineering design. From a retrospective, these researches were running too far ahead before I finally shaped the research themes of this PhD thesis. In the data processing of these researches, another problem was identified. I intentionally made the number of participants to the minimum possible level. Since

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[16] MDS: MDS is one of several visualization methods now widely used in all the sciences-methods that look for patterns in numerical data and display those patters graphically. You'll see multidimensional scaling called smallest-space analysis. That's because MDS programs work out the best spatial representation of a set of objects that are represented by a set of similarities. (Bernard, 2011, p. 352)

[17] At that time, my focus was engineering design capacity building which seemed to be a technical problem.

[18] In statistics, the binomial test is an exact test of the statistical significance of deviations from a theoretically expected distribution of observations into two categories. One common use of the binomial test is in the case where the null hypothesis is that two categories are equally likely to occur (such as a coin toss). Tables are widely available to give the significance observed numbers of observations in the categories for this case. However, as the example below shows, the binomial test is not restricted to this case. (Howell, 2007) This method is used to distinguish which approach of improving engineering design is more effective perceived by the respondents.

these participants were all voluntary there was no mandatory requirement on how serious they should respond to my surveys and behave in the interviews. When the questionnaire sheets were returned to me, I found many of them were treated carelessly. For example, some respondents marked all of the identified approaches of improving engineering design effective. It did not mean that they should not do so, but it at least reflected that they did not take the questionnaires seriously. As a consequence, it made my already limited sources of data even more scares. However, these researches enhanced my understandings of engineering design in CGN.

I consulted this problem with a serious participant Mr. F who later became one of my partners in the company project of improving engineering design. One reason for this was that since all the participants knew that their involvement was completely irrelevant to any company schemes or projects, they treated such participations as a waste of time. No substantial influence to the company could be generated from these voluntary projects. Therefore, I began to think of incorporating my PhD study into some company projects, but at that time I did not see any apparent opportunity that the company would support this attempt.

In 2013 the influence of the Fukushima accident was still vivid, but CGN was busy constructing its already started CPR1000 plants. Engineering designers were full-loaded with project tasks and, importantly, the company did not think it necessary to make any changes to its engineering design because at that time the established engineering design habits and system were sufficient to support its business at hand, and it was expected that new projects would not be approved in the near future. The development of the Chinese Gen-3 nuclear power plants was not in the company's agenda at that moment.

In the middle of 2014 nuclear power development appeared to warm up again. The economists reiterated that nuclear power was the solution to the environmental problems at the lowest cost without compromising China's economic growth. Regarding to CGN, restarting the national nuclear power construction plan was an opportunity to solve its own problems. One by one, the CPR1000 projects reached to their testing and commissioning phases. Therefore, CGN designers' workload dropped dramatically. If this situation continued, CNPEC and CNPDC engineers would have no work to do. In this circumstance, CNPEC tapped into some non-nuclear power businesses, such as some solar power plant projects and some engineering consultancy services to the Chinese railroad construction projects. But in terms of business value, none of these smaller businesses was enough to maintain a stable income for the company's employees. On one hand, CGN was eager for new nuclear power projects of whatever kind both domestic and overseas. On the other hand, there was no evidence indicating that the central government was going to compromise its mandatory requirements for the utilization of Gen-3 nuclear power technology for future nuclear power constructions in China. The AP1000 technology is not in the hands of CGN, and the power capacity of the EPR unit[19] is too high for those economically less developed provinces. All these factors pushed CGN to make some changes, especially to its engineering design, in order to be alive in the market.

The company decided to start a reform to reshape its engineering design. According to the official interpretation, the aim of this reform concerning engineering design is to transform the contractor-typed design based on authorized duplications to an engineering design that starts from R&D activities.

An internal newsletter was issued asking for employees' proposals to direct this reform. In addition, employees were encouraged to form research groups and hand in project applications. All accepted applications would be granted some company funding and importantly such projects were all listed in the yearly company research scheme.

I found it a great opportunity to incorporate my PhD research into this company program. I persuaded some engineers to form a research team to meet the requirements of application. I thought it would solve the problems appeared in 2013. The team consisted of 6 members. Beside me, Mr. F a CGN commercial engineer, Mr. W a CGN project manager, Mr. G a system designer, Mrs. S a civil work designer, and Mr. L a main equipment designer were the team member. Since all of us knew each other in the Taishan Project, we decided not to appoint a team leader. Compared to the designers and the project manager, Mr. F and I seemed to be less busy and were based in Daya Bay – where CNPEC's headquarter locates. We were chosen to be the coordinators. In fact the members were all well-chosen because I intended to mix different perceptions of engineering design. On top of that, they are the people that I think resourceful, active and responsible from my observations.

In the first meeting of our team held in Daya Bay, I proposed that our research for the company should take the social concerns about nuclear power and other types of energy technologies into consideration in the sense that even the traditional schools of engineering design depicts a design starting from the shaping of a concept which is an engineering interpretation of certain social concerns and demands. I thought in the future, CGN was going to perform a regular engineering design which should not be a copy and perhaps the company might participate in more non-nuclear power projects. Based on the perception that the company needs to go back to the original meanings of engineering design so that it will be prepared for future changes, I thought my proposal would attract attention. However, I did not insist on my proposal, because I knew that we must work out a topic that would attract the

[19] The EPR Unit capacity is designed to be 1700 MWh, 1.7 times of the CPR1000 and AP1000.

attention of our higher management otherwise the project would never be granted. Pure academic interests would not help us in getting research funding from the company. It was not a surprise that our team members vetoed my proposal, due to the fact that we all found such a topic to be too far away from our engineers' self-recognitions as nuclear power engineers. We needed a more practical topic.

In the middle of the meeting there were two proposals which we thought appropriate: first, a study on the process of engineering design, and second, a study of the relationships among engineering design and CNPEC's other engineering activities, such as procurement, construction management and commissioning. The first topic derived from a consideration that the engineering design process at that time had a lot of problems that reduced its efficiency. On top of that, it was believed that the optimization of the process would consequently lead to the improvement of the quality of our design products such as the correctness of drawings. The second topic originated from a speech given by one of our top leaders saying that engineering design should no longer be just one phase of a nuclear power plant construction project rather it should be the leading work of all the engineering activities. In this respect, it might be worthy of our effort to study how this leading status means to CNPDC, and to the other departments in CNPEC.

Personally, I supported the second topic, because at least it could contain some aspects of the social dynamics of engineering design with other engineering practices. But some of the group members opposed this proposal because such a study would include too many interfaces that all of us wanted to avoid.

Mr. W did not agree with the first topic because the refinement of the engineering design process in CGN's project management experience had long been a critical job of the quality assurance engineers. Tapping into this topic, meant that we intruded into another established discipline. Mr. W's understanding of the company's call for proposals was that the company wanted to ask for possible directions of changes not a repetition of other's work with another method. In fact, Mr. W vetoed all the two proposals that we had at hand. Because, the hidden meaning of his opinions was that we should not criticize other's work in the name of research especially in those field where routines had been established. A safe strategy was to criticize our own work, as he implied.

Finally, we abandoned all of the initial proposals and turned to think of something that featured engineering design. The company launched its knowledge management system in February 2014 and decided to use this new system to systematize CGN's engineering knowledge gained from its CPR1000 construction experiences on one hand, and to foster technological innovations inside the company on the other hand. But at that time, the computer-based system was not completed yet. Only a framework had been built. A large proportion of its content needed to be filled in. Since engineering design is considered as a form of knowledge production in CGN, this knowledge management system became the topic of our focus. Mr. F mentioned that the knowledge management system was headed by the science and technology management department of CNPEC. Considering Mr. W's implication, we needed to consult that department to make sure. Otherwise, as Mr. F later mentioned, it would generate a misunderstanding that we intended to criticize their work rather to help them. Importantly, we also knew that our potential research funding was administered by that department.

After this first team meeting, Mr. F and I made an appointment with the head of the science and technology management department. In our informal meeting, we explained our intentions to him and we asked for advice. The head of the department acknowledged our ideas, and he even admitted that the system was almost empty at that time. Therefore, he directly asked us to help his department with the knowledge management system. Specifically, two tasks were assigned: first to categorize the knowledge in CNPDC and second, to show him how this system could be used to generate more technological innovations.

We organized the second team meeting to make our research proposals in one of CNPDC's meeting room about 30 kilometers away from Daya Bay. In this meeting, we worked out our proposal without a time consuming discussion, because we had clear tasks, and we realized that the methods used in my self-motivated researches can be directly appropriated in this research. The substantial work for us to do was to perform some questionnaire surveys. Data processing for us was not a problem. With company supports, we were almost certain that the respondents would cooperate seriously.

However, there were still some modifications in this company research project to the self-motivated project. First, instead of asking what are the skills needed and personal characteristics represented in engineering design, the respondents were asked what is the knowledge used and what is produced in their work. After this identification procedure, a pile-sorting program[20] can be run so that the items identified can be categorized by a computer automatically. This would produce a list of knowledge items covering all engineering design disciplines and divisions in CNPDC. The two dimensional MDS map was abandoned in this research because we expected that the managers of CNPEC prefer definitive results rather than relative relations. The second modification was in fact a change to both the second task assigned by the head of the department and the initial self-motivated research. Instead of studying what are the most effective approaches of fostering innovations, we studied what knowledge is considered to be more innovative.

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[20] A computer program mentioned in Bernard's (2011) book used to perform grouping of similar concepts. In the research project knowledge is considered as a concept rather than a physical document.

The second modification derived from two considerations. On one hand, innovation refers both to engineering practices and knowledge. (Sharif et al., 2012) That is to say that we need to know what is considered to be innovations in CGN. From the binominal test, it was expected that not only we would know what would be regarded as innovations in CGN, but also we could identify what kind of innovations were more appreciated. Due to the fact that the knowledge management system had been installed, provided that we could work out a mechanism to evaluate innovations in CGN in terms of their perceived significance, it is much easier for us to propose to the science and technology management department to add one module in that system. On the other hand, we tended to think that encouraging innovative practices required a rewarding mechanism inside the company. But that was the topic that we did not want to be involved in because it would bring in one more interface into our research – the financial department. Nevertheless, with an evaluation of the significance of innovations, we thought, the answers to how to encourage them – especially some financial rewarding toward these attempts – were not so difficult to work out.

As we wrote in the research application document, the research was designed into three phases – a preparation phase, a data collection phase, and the last reviewing and report writing phase. The split of tasks, the making of a time schedule and the assignment of tasks within the team members, were done as a routine for all of us because we were accustomed to CGN's habits on such matters. The three designers were responsible for preparing questionnaire sheets and collecting data and the three CNPEC engineers, including me, were responsible for the report writing and other associated matters. It was originally planned that the research project would last for one year till the mid of 2015. But later, some force majeure compelled us to complete our research project by the end of 2014.

Our research application was accepted by the general manager's office. Including our team, there were all together 14 research teams chosen from more than one hundred applications. Other research topics about the company reform included, a study of CGN's future information management system in the big data era, a market oriented study on CNPDC's potentials of non-nuclear engineering projects, and a human resource study on the encouragement of young engineers career development, just to name a few. Till October 2014, the reform studies were running in the mode as it was planned in the official announcement. Each month a meeting was held by the general manager's office. Representatives from each of the research teams attended the meetings to report to the deputy general manager of CNPEC in charge of this reform study program their progresses and difficulties. According to the general manager's office, the purpose of such a monthly meeting was not just for reporting, but for making a forum that researchers could learn from each other. The deputy general manager told us to feel free on our researches and explained to us that it was not mandatory to reach to our conclusions in a hurry because the company would decide on how to draw a general conclusion from the diverse findings of our researches. In this respect, according to my understanding, the deputy general manager's words expressed the company's intention of a centralized control over all these researches.

4.3. MAIN FINDINGS OF THE INITIAL ACTIVITIES

The readers of this chapter are advised to refer to the Appendix A of this thesis. In this appendix, I only list the main results of my self-motivated research due to a consideration of the company's rigid censorship[21] regulations on the publication of academic research reports. Since the self-motivated research and the company research are methodologically similar, I present the findings from both of them in a synthesis.

Since the company research project studied knowledge while the self-motivated project studied engineering design capacity, those elements related to the personal characteristics of designers were no longer identified in the company project. But an increasing number of technical terminologies emerged in the category of the technical knowledge items. In addition to the self-motivated research project, knowledge about the process of design in CNPDC played a more significant part. Also a group of knowledge named "knowing of company organizational structures" followed.

The two researches both revealed that some designers think commercial knowledge such as the understanding of the contracts is important for engineering designers while others do not think the same. On the contrary, they claimed that commercial engineers should learn more engineering knowledge.

The understanding of technical standards and environmental health and safety legislations is regarded as very important, because that kind of knowledge is the criterion to measure the quality of their designs and the safety hypothesis of a nuclear power plant.

Professional communication skills appear in both projects. All these items emphasize on the internal communications among the engineering disciplines inside the company, rather on the interaction with the society outside.

There are differences between the respondents from different design divisions, but these minor differences only appear when specific disciplinary terminology is used to describe individual technical backgrounds.

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[21] The censorship is performed by the Intellectual Property Office and the Confidentiality Enforcement Office. It is required that anything related to the company's internal policy cannot be released without their approval.

The second part of the two research projects produced complementary results. In the company research project, it was shown that patents, technical modifications leading to improvements of the functionality are considered as the most significant innovations, modifications to design procedures and methodologies are treated as less significant, and solutions to the non-conformances of manufacturing and construction activities are treated as the least important, the same to the introduction of new equipment and technics to the nuclear power plant.

In the self-motivated research, I found that improving engineering design can be achieved in two ways. First, learning by doing seems to be favored by both our managers and engineers. That is to say, the best way of improving engineering design is to work for a real life engineering project. Another approach can be expressed as a knowledge transfer between the mentor and apprentice. This approach emphasizes gaining knowledge about the reason for practices. Learning by doing is considered as more important. Because in a circumstance of tight scheduling control, knowing what to do is more important than knowing why it should be done in that way. However, this preference seems to be contradictory to the ranking of technological innovations. That is to say, different value criterions are used on evaluating engineering design as knowledge and as a practice. In the ranking of innovations, scientific value is adopted while in practice economic value seems to be the yard stick.

4.4. SOME LESSONS LEARNED

The head of the science and technology management department was not satisfied with the first part of our research because did not agree with our considerations of connecting knowledge with practice. Even though we roughly identified 200 sub-categories of knowledge, he straightforwardly pointed out that this was not what he wanted. He reminded us that any already existed bibliography classification systems are more commensurate than ours. What he wanted was a complete catalogue of the methodological documents issued by CNPDC and the references used in CNPDC's engineering design relating to all the engineering documents – drawings and reports – issued for the construction and manufacturing. Therefore, in his mind, knowledge management was perhaps a system of bibliography, and perhaps what he wanted us to do was to digitalize our documents and drawings, which had already been done by CNPEC's document center inside the project management department. As such what he termed the "implicit knowledge" would become more explicit and then could be utilized conveniently. The relationship between knowledge and practice was not the concern of the department head.

On the contrary, he was quite satisfied with our methods and results of studying innovations. The ranking system looked like a systematic peer view of the newly emerged documents. One feature of the binomial test is that it can systematically reduce randomness. In this respect, such an evaluation gives an image of fairness.

Considering that only 16 experts were invited to the evaluation but a distinguishable result appeared, with serval hundred names of experts in their data bank, he was quite confident that it was quite a convenient method for him to perform more precise evaluations. Importantly, as a PhD in computer science, he realized that adding a binominal test module to the knowledge management system was not a difficult task.

When we were considering whether we should continue our study on the first part in order to make a more consummate dendrogram of CNPDC's knowledge, or we should corporate with the "big data" team to make this study move forward, we noticed a change in the implementation of the company reform study program. In November 2014, we were not informed to take part in the monthly meeting. According to the general manager's office that such a meeting was canceled. We telephoned the contact person in the general manager's office, in that phone call we were told that the deputy general manager in charge of this program changed. The new deputy general manager in charge considered this program less important. Because in his mind, the critical factor leading to a successful company reform is what he called "top level design".

Later, I attended one of the new deputy manager's training courses. His philosophy of company reform was based on the following expression "We survive on technology and we thrive on low costs". We were told that he worked out this expression from his understandings and experiences, and this sentence served as the title of his speech to all CNPEC engineers. Unlike the former deputy general manager who asked for employees' opinions, the new deputy general manager adopted a traditional approach to channel company reform – top-down administrative push. He promulgated some general norms. And then these norms were broken down into several disciplinary topics, such as how should CNPDC respond to company changes, and how should the procurement department. Inside the departments, such questions were broken down to a further degree into its branches and even further to its small groups until perhaps one question reached to a specific engineer. Answering such questions became a part of engineers' job. In this respect, it became an obligation rather than a voluntary participation.

Under this scheme, I don't think that new ideas will generate because the conclusions have been made in advance. What engineers have to do is to find some practices that have already existed and tailor them to fit in this new scheme.

In December 2014, two months after the shift of the tone of this reform study program, we received an email which asked us to complete our research by the end of the year. It said that all teams must submit their research reports to the general manager's office before the deadline. The result was that our reports would be kept as company archives in the document center.

In 2015, along with some good news of China's future development of nuclear power, the company seemed to be back on its old routine again. People became busy as usual, the designers retained their confidence and project control engineers were considering shifting to either an international project or the HL1000 project. It looks as if the HL1000 project itself represents a full-scope company reform, and the former reform discussions which lack a concrete project backing have been shelved.

What I have learned from this experience is that improvements of engineering design inside the system may not fulfill CGN engineers' pursuits of becoming good engineers. In order to get company recognition engineers normally compromise to the organizational culture that absorbs Chinese engineering traditions. Criticizing what is wrong can be interpreted as criticizing the culture. This is what CGN engineers try to avoid. They tend to find problems in the field that they are familiar with while others are not. In this respect improvements can be done as minor modifications to the established traditions and habits. However, what appears in this case is that company's determination of making improvements is not firm. Engineers' motivations can be used to serve its purpose of adapting to the changing market conditions. When evidences show that such conditions remain unchanged, engineers' service has no use. Sometimes the traditional bureaucratic or technocratic approach of adjusting organizations and procedures is considered as more effective. As a result, I tend to conclude that engineers' personal pursuits of becoming good engineers cannot rely on the company.

Perhaps "improvement" is not the proper approach to make good engineers. Change seems to be the correct keyword. These changes might have already existed in our lives.

CHAPTER 5. THE HUMAN SIDE OF NUCLEAR POWER ENGINEERING

This chapter portrays some engineers' personal engagements in CGN's nuclear power engineering projects. Due to the varieties of their personal backgrounds and their specific tasks performed, CGN's transitions in engineering design can be reflected in its engineers' personal transformations. The figures appear in this chapter are far from prominent, in terms of prestige, compared to the figures mentioned in Chapter 2. It may not be proper to say that any of them have brought about any changes to this company but they have all experience some changes in their careers. Therefore, through their experiences, their efforts in changing themselves relating to changes of the company can be presented and studied.

5.1. A SYSTEM DESIGN ENGINEER – MR. G'S EXPERIENCE

5.1.1. A DESCRIPTION OF NUCLEAR POWER SYSTEM DESIGN

In CGN's division of labor, specifically regarding to engineering design, there is an engineering discipline called "system design". The major tasks for the system designers are to construct the entire material and digital flows of a nuclear power plant. It is their job to make a system out of assemblies of equipment. This definition can be elicited from Mr. G's – one of our system designers – words on his tasks in the JDO (Joint Design Organization between AREVA NP and CNPDC) for the Taishan nuclear power plant's design:

> "My position was very important in the JDO. Firstly, I was in charge of the RCP system. It means the entire nuclear steam generation and heat exchange system, not just the Reactor Coolant Pump. It includes the steam generator, the pressurizer, the piping and the pumps. And some control units. Secondly, I also took some responsibility of design management. Therefore, there were a lot of discussions about my tasks in the negotiation of the contract." (Appendix, B)

5.1.2. THE TRANSITION FROM A STUDENT TO AN ENGINEER

Since this discipline of engineering design includes knowledge about nuclear fission reactors and nuclear physics sciences, engineers work in this discipline are mostly those students educated by the Chinese technical universities with nuclear physics and reactor engineering majors, such as Tsinghua University, Xi'an Jiaotong University, and Shanghai Jiaotong University. Mr. G is a graduate from Tsinghua University with a Master's degree majored in reactor engineering.

He was recruited by CGN in 2004 when the renaissance of nuclear power in China has just begun. Perhaps it was because of his cooperation with CGN in his postgraduate research activities in a joint R&D project between Tsinghua University and CGN, he was first hired in CGN's Technology Center – an entity affiliated to the headquarter. At that time CGN's engineering design entity CNPDC has not yet been established. In Mr. G's interpretations of the establishment of CNPDC, it symbolized CGN's first engineering transition from an owner-typed nuclear power plant operator to a nuclear power engineering company which started to build nuclear power plants based on its imported technologies and engineering modification experiences gained from its operation.

> "CNPEC was established in the year 2003 and at that time the Technology Center was an independent entity in the CGN group for the purpose of providing technical consultancy services to new-built plants and technical upgrade of the existing units." (Appendix, B)

> "Later when CGN decided to set up its design institute, people employed in the Technology Center were distributed to the divisions of this newly established design institute namely CNPDC. Therefore, the Technology Center became the predecessor of CNPDC's Nuclear Island System Design Division and the Rector Engineering Design Division. The conventional island design division was at the beginning a joint group consisting of some engineers dispatched from the GEDI (Guangdong Electricity Design Institute) and some engineers majored in conventional island engineering who originally worked in CGN. Such an arrangement of the conventional island design team was in fact a consequence of CGN's investment to GEDI. It was in 2005, when the Ling Ao Phase 2 project started." (Appendix, B)

His participation in this round of company reform was not only manifested by his change of position in CGN's organization but also presented by his descriptions about the different types of work he was assigned after the change of position. In his own words, before 2005 his work can be categorized as "learning" – such as the R&D project he participated in. It was in CGN's first cross-provincial project, the Hongyan River project, which started in 2006, his work was changed into "doing". (Appendix, B) The Hongyan River project held a sense of a milestone to CGN. It was the first CGN's project outside Guangdong province and more specifically outside Daya Bay area. It was also the first project in which its design was completely performed by CNPDC. The most important feature of this project is that the technology used in this project is a Chinese brand named CPR1000 – a CGN's derivative of AREVA NP's M310 technology. This represented CGN's capacity of performing Gen-2 nuclear power plant's engineering design, even though before that CGN's plant construction entity CNPEC had already gained abundant experience in nuclear power plant's construction management, equipment installation and commissioning.

5.1.3. THE RELATIONSHIP BETWEEN KNOWLEDGE AND PRACTICE

The logic underneath his understanding of engineering design derived from his interpretation of the relationship between scientific knowledge and practice. As Mr. G put it:

> "It was in the Hongyan River Project, I first learned what is indeed engineering design for a nuclear power plant. Scientific knowledge does not equal to the capability of engineering design." (Appendix, B)

According to Mr. G, engineering design is a work which transforms knowledge into practical usage. Even though R&D activities can be regarded as a form of engineering design, such work only points out future or possible usages of certain knowledge which is theoretically founded, but real life engineering design, at least in CGN, is not founded on this hypothetical basis. Only justified knowledge by previous experiences can be used in nuclear power plant's designs. Therefore, for him, improving CGN's engineering design requires more practices. This utilitarian perception of knowledge is in line with the Confucius' sayings about "learning" and "doing" which Mr. G, quoted to support his opinion.

> Mr. G quoted: "xue er shi xi zhi, bu yi yue hu."[22] He further interpreted: "Studying is tough, while practicing is happy." … …"Studying the knowledge is tough but when you use the knowledge to solve problems it turns out to be happy. When you practice, you may gain some feeling, and such feelings reflect enhancement of your skills."(Appendix, B)

Good design in Mr. G's perceptions equals to the making of a precise blueprint on which the system of a nuclear power plant can be built and the equipment can be assembled without any deviation from it. This requires abundant experience of problem-solving so that the designers know exactly what kind of knowledge corresponds to the questions to be solved and such knowledge should be justified knowledge. This demanding requirement would have some conflicts with real life engineering design experiences, as Mr. G also realized.

Due to the fact that the CPR1000 nuclear power plants are to a large extent licensed copies of the French M310 plants, it indicated that Chinese designers have limited chances of getting first-hand experiences of similar engineering designs. Therefore,

[22] "It is indeed a pleasure to acquire knowledge and, as you go on acquiring, to put into practice what you have acquired."(Ku, Hung Ming's Translation, 1898, in The Discourses and Sayings of Confucius)

in order to get such valuable first-hand experience, it seems that the designers have to be put into the situation when the original questions first appear. Because even though in a retrospect the solutions can be understood through learning, designers cannot acquire the sensitivity of the knowledge from established answers. That is to say the understanding a solution to a specific question does not equal to acquiring the ability of solving similar questions.

5.1.4. A GOOD METHOD OF IMPROVING ENGINEERING DESIGN

In order to resolve this tension between "learning" and "doing", a specific program under the EPR technology transfer project, a Joint Design Organization (JDO), was generated. The intention of this program was to set up a learning-by-doing approach which was considered as more useful than the document transfer approach, in assisting the licensee of the technology transfer contract to acquire technical know-hows and know-whys.

> "When CGN negotiated with AREVA and Westinghouse about the EPR and AP1000 technology transfers, the JDO was included as a major theme of such technology transfer projects. This means that our top management has realized what capacity building is. So CGN intentionally and systematically dispatched people to AREVA's design organizations to learn from them. As a consequence, those who were dispatched got some in-depth understanding of what is engineering design and what is a normal engineering design process, and even what is engineering design management. The JDO covered a wide range of our engineering disciplines." (Appendix, B)

According to Mr. G, the result of the trainings seems quite satisfactory. As he put it:

> "Each job descriptions about the JDO positions depicted what was the role of the designer, and his or her corresponding capability. The organization of JDO required detailed planning. At that time CGN's experts concretized such a planning. This is critical. The 180 designers dispatched to JDO were the seeds planted to AREVA's land. Later these seeds took roots. After that, we were transplanted back to the land of CGN. Now we are still nurtured by CGN, but some are given more care while others may receive less attention." (Appendix, B)

On the AREVA side, it seems that the adoption of the learning-by-doing approach is also regarded as a success. As the AREVA technology transfer manager Mr. M put it:

> "That is why I say to you the best way to learn is to be obliged to do the job. He (a designer) was involved in such a detailed design job. But to

> do a detailed design you have always a basic question about the reason why. And obviously when you do detailed design you learn something about the basic and conceptual design. So JDO is a good thing." (Appendix, C)

As Mr. G said in the interview, he was an important member of the JDO not just because in the management hierarchy he was appointed as the Chinese technical manager, but because he performed different types of tasks that the JDO could provide. This indicates that he has accumulated a lot of experiences from varieties of problem-solving tasks.

> "A system designer is a synthetic person. According to what I have heard from EDF, the grown-up of a system engineer takes 10 years' time. This person is required to shift from varieties of positions. In the end, this person can finally be placed to the position of system synthesis. So when I did my job as the designer of the RCP system, I became quite aware of the safety issues of the nuclear power plant, the reactor engineering, the digital control engineering and the equipment. I needed to interact – setting up interfaces – with them voluntarily. So as a system designer, my design is a design of the process and at the same time, I do some job which should be done by the digital control people. This kind of job shifting or synthesis in CGN is relatively blank, because we normally think a system designer should not tap into the digital control field etc." (Appendix, B)

It seems that time is a critical factor to accumulate abundant experience, and a competent system design engineer can be finally nurtured over time. But another question appears: "is abundant time along enough?" From Mr. G's words, I think it may not be the case. As he mentioned, there is a question of transplantation, in the sense that whether what is learned from AREVA can be applied in the design work in CGN. After the JDO had completed its job in France, CGN engineers returned back to China, and diffused into CGN's design divisions. Some of them consider that their experiences gained in the JDO attract CGN's attention which normally indicates a successful transplantation but some may think that their learning useless, especially, regarding to changing CGN's engineering design practices with AREVA as a model.

Mr. G seems to categorize himself as a successful case:

> "In AREVA I mainly concentrated on the basic design of the Taishan project, but when I returned back to NID (Nuclear Island Design Division), I faced a lot of problems derived from the detailed designs of several projects. Still there were some problems related to the construction and commissioning of the on-going projects and also some

> problems of equipment manufacturing. As a system designer I need to make analysis of whether some non-conformances of the manufacturing to the design would impair the functional requirements of the system. In these three years, I gained more detailed experience on solving site related engineering problems. After the Fukushima accident, I encountered engineering problems that aimed to the improvements of the already built units such as the add-up of a high positioned water reserve for the Ling Ao Phase 2 units. I felt that what I accumulated in JDO, the methodological knowledge and the understanding of the design process, helped me a lot in the problem-solving of these improvement designs and other site related detailed design issues." (Appendix, B)

5.1.5. MR. G'S ATTEMPT OF TRANSPLANTATION AS A TECHNICAL LEADER

As a chief engineer in NID, Mr. G started his own small project in changing CGN's engineering design. What he has done is a mapping of the missing knowledge in his division with a comparison to what he has learned in AREVA.

> "After I came back as the chief engineer, I am in the position to organize capacity building for my fellow engineers. I think that I have a clearer picture of what kind of capacity is required in my team. So I organized a cross disciplinary capacity building across different branches in my division. I identified capacities according to my own standard and motivated people who were willing and suitable to participate. My standard derives from my experience gained in AREVA. I compared the stereotype of a system engineer in AREVA to ours, and found out what is missing in our organization. Then I intentionally triggered some sort of a voluntary capacity building campaign. This attempt lasted for 3 years, from 2011 to 2014 before I left NID."(Appendix, B)

The motivation of such an attempt is based on Mr. G's feeling that due to the relatively shorter history of CGN's engineering design and the higher percentage of young engineers in CNPDC, the company's accumulation of technical knowledge is rather scares. Compared to AREVA which has dedicated to the design of nuclear power plants and the manufacturing of the main equipment for several decades, it seems that CGN has to catch up.

> "Their technology development is standing up on their predecessors' shoulders. They keep systematically their experiences and knowledge. Scientific, technological and methodological knowledge are all well documented, and looking into their industrial codes and regulations, they are more consummate than ours." (Appendix, B)

5.1.6. MR. G'S IDENTIFICATION OF CGN'S PROBLEMS

During the interview when Mr. G addressed his emphasis on the accumulation of knowledge, I was confused why he would not emphasize on the generation of knowledge. This confusion derived from my reflections on his descriptions about his work. It seemed to me that he had never given any detailed examples of what kinds of technical problems – a calculation on the break of a pipe or a choice of a pump for example – he had ever solved in his job either in China or in France. Therefore, I felt hard to connect his job with the knowledge he referred to. He knew that I was also educated to be an engineer. I thought he should have known that I might be able to understand some engineering fundamental knowledge. His descriptions of his work were focused on the scope instead of the content. Therefore, it made me to ask him questions about his daily routines such as how many hours he spent on calculation and how many hours he used on making drawings.

> He replied: "In China, normally we rely on meetings to solve problems. It takes up to 50% of my working hours. Here as you know, we are either the coordinator or being coordinated." Later he added: "After I came back and was appointed as a chief engineer, most of my time was used on attending meetings. In average I attend more than one meeting per day. The numbers of emails once increased to 300 per day at the maximum." (Appendix, B)

Mr. G seems to be critical about his daily routines because he thinks design engineers should spend more time sit by their desks calculating or making drawings. He expresses his objection by a comparison to his daily routines in France.

> "In France designers attend fewer meetings. Every day I calculate, make documents. I call to my colleagues as a kind of normal communication, but, very few meetings. I cannot make assignments for other people. I simply do my own job. So I have more time to think and to do some concrete work." (Appendix, B)

I had similar confusions in the interviews with other CGN engineers. They seem to be quite clear with their scope of work but cannot give detailed illustrations on the process out of which the problems are solved. Perhaps the real problem-solving process appears in the numerous meetings our engineers are asked to take part in. It looks as if all problem-solving activities in CGN are a kind of collective work.

I ascribe the cause of this phenomenon to CNPEC and CNPDC's organizational structure. In CGN as I illustrated in Chapter 3, the definition of the scope of engineering work relies on two managerial dimensions. The project dimension can be seen as a technical dimension which is stipulated by the sequence of engineering tasks, for example design is put ahead of procurement and procurement is followed by installation and commissioning. The administrative dimension can be seen as a disciplinary dimension which indicates connections among technical disciplines. Such as the system design is connected with equipment design and digital control design. Therefore, we see multiple interfaces between designers and other kind of engineers and among designers. This structure enables one designer of a particular engineering discipline to work on multiple projects, but at the same time, it also restricts individual designers to perform some cross-disciplinary work. For instance, a designer of a pump for project A is normally also a designer of the same pump for project B, but only in limited situations he or she can be a designer for some piping of project A or B even if he or she may also be technically capable. In this respect, engineering designers in CGN are quite sensitive to their scope of work, which limits their chances of facing with different types of engineering questions.

Regarding to this type of organizational structure, it seems that system designers like Mr. G are rather difficult to be nurtured. An even the more problematic question associated with this structure is that along with their promotions – form engineer to senior engineer and to chief engineer – capable engineers are given chances to solve more problems, but they are in reality getting further to practical engineering activities. In this respect, they are gradually turned into technical commentators – the ones who make decisions based on making comments to other's work.

5.1.7. IDENTIFICATION OF CGN'S PROBLEMS BY AN AREVA MANAGER

In fact, I am not the first person to notice this tension between organizational structure and the enhancement of the problem-solving capability of our engineers. But discussions about such issues are performed informally in casual conversations among CGN employees. An external observer Mr. M from AREVA expressed his opinion about this phenomenon:

> "I now need to make an inquiry. Where are all these people? The NIEP people (on the AREVA side) told me that some people who were trained in the JDO are now not working for the EPR project. You miss a lot of things by doing like this. These people will forget something, or they might leave the company in the worst situation. But after five or six years they move back to the design work they will have lost some knowledge. You have to keep these competent people in a growing curve in term of the load of work. In this case they will get better and better. That is also a project management concern. To choose the good guys and put them again and again on the technical positions." (Appendix, C)

5.1.8. A TYPICAL PATH OF CAREER DEVELOPMENT

In 2014, Mr. G experienced his most recent change in CGN. He was transformed from a designer to the full-time technical manager of the EPR technology transfer project. He told me that the latest engineering accomplishment he had made to CGN before this transformation was his design in CGN's engineering modification to the already built Gen-2 nuclear power plants. This modification is implemented by adding up a high positioned water reservoir near the nuclear power plant. In fact, it is a CGN's reaction to the engineering study of the Fukushima accident. In the Fukushima accident, the emergency diesel generator did not function because it was submerged by the sea waves which exceeded the design limits of the water-break which was supposed to prevent submerging. Therefore, the Fukushima accident was classified as a beyond design basis accident. From a design perspective, coolant circulation relying on emergency diesel generators is no longer considered as safe enough. In this respect, the concept of passive safety, symbolized by the AP1000 design, get its favor among Chinese nuclear power engineering designers. Since there is no way to build a huge water tank on top of the concrete dome of the already operated nuclear islands, the only modification that may generate the same effect is to build a water reservoir on the nearby mountains. It is contended that gravity would produce enough pressure to circulate coolants inside the primary loop. Therefore such passive circulation will prevent the reactor core from melting caused by the residual heat. This passive safety approach is decided to put on use for the reactors currently situated at the Daya Bay site. Mr. G is the chief designer of this modification, and this approach is going to be adapted to CGN's future nuclear power plant engineering designs.

Mr. G considered this experience in the adding up of a water reservoir as a relatively comprehensive exercise of his knowledge learned over the years.

Here Mr. G's career development path can be summarized into three stages: stage one, he was transformed from a fresh graduate from Tsinghua University to a design engineer in CGN; stage two, along with his accumulation of knowledge and practical experience he was given more tasks and promoted to a chief designer; stage three, due to his experiences of working with AREVA and relatively comprehensive knowledge about nuclear power reactor engineering he was chosen to be a technical manager. But in this new position, he left engineering design and his division NID.

From my interview with Mr. G, I was told the only "non-nuclear power" engineering design he had performed. It was a radiation protection design for a petrol chemical company. Radioactive rays are used in the chemical industry for detection and monitoring purposes. Therefore, these radioactive sources are required to be shielded. CNPDC is among the few entities licensed by the Chinese authority to perform radioactive shielding container designs. Therefore, CNPDC got a contract for this special type of container design. It was a chance for Mr. G to practice his knowledge about radiation protection which was from his own interpretation a work for environmental protection.

From my observation, Mr. G is a person who is craving for new knowledge. His philosophy of knowledge can be portrayed as learning followed by doing. Scientific knowledge is placed at a higher position than practice even though he admits the importance of practice. As far as I can interpret his meaning of doing, it is perhaps giving knowledge some utilitarian value. This means that his motivation of learning derives from utilitarian purposes. The purpose here does not necessarily equal to the monetary value. It can be a factor related to his career promotion or social status. When we travelled to France for a meeting with AREVA, I noticed that he brought himself a PMBOK – a project management book – to read on the flight. When I asked him about the reason to do so, he replied that he should learned something about scientific project management, for he did not want to present to his counterpart on the AREVA side an amateurish impression.

5.1.9. A DIVIDE OF IDENTITY – PROFESSIONAL VS. SOCIAL

Mr. G is a golf player. But it is extremely paradoxical to determine whether this hobby can reflect Mr. G's environmental awareness as a person not as a professional engineer. Playing golf is considered as a modern healthy game after its introduction to mainland China in the early 1980s. At least Mr. G thought so, and he even volunteered to teach me how to play this luxurious game. On one hand playing golf can be considered as an environmental friendly sport, due to the fact that it brings human closer to nature. On the other hand, it represents a higher social status of the player. Playing golf is an expensive game in China, in the sense that a golf course takes a large area of land which can be used for other purposes rather for the entertainment and recreation of the newly emerged richer class. This tension between the usage of land for the construction of golf courses and its alternatives seems to be intense in the Chinese populated cities such as Shenzhen.

It was reported in the Shenzhen local evening news on January 18, 2013, that one golf course built in 1985 was about to expire its land lease in half a year. (Shenzhen Evening News, 2013) Since the land is now situated at the center of the city due to the over 30 years' expansion of the city's landscape, whether to grant a renewal of the leasing contract between the government and the developer has been put to a public debate. The government has finally decided not to prolong the lease of this piece of land for the golf course but to regenerate it to a public park. This case triggers some of my thoughts about Chinese public environmental awareness. I would consider the final result regarding to the transformation of this piece of land into a public park as a triumph of the general public's environmental concerns about their lives in this city.

In this case it revealed some aspects of the social tensions underneath environmental consciousness-raising in China, in that whether environmental consciousness is a symbol of elegant personal hobbies or it is a basic demand of the general public. From an economic perspective, changing this piece of land into commercial or residential buildings for public use can also be a fair alternative, but making it a park which has less financial value is in fact a best solution for public benefits. In this respect, the final decision seems like a generous consumption instead of an economically minded production. It must be hard for the city government to make this decision, but I think it is a good choice because it at least changes an unfair distribution of limited resources associated to the use of this piece of land. In the sense that before this transformation, the chances of getting close to nature were sold to those who could afford this privilege at an extremely high price, but after that, the previously privileged chances were turned common for all citizens of Shenzhen. This type of transformation refers to Lewis Mumford's (1970) notion of ecological economy and this type of consumption is in fact what needs to be encouraged.

Mr. G's hobby of playing golf derives from a benefit provided by CGN. CGN has built a small golf course near the nuclear power plant in Daya Bay. Compared to the market price, CGN employees can use this golf course at an extremely low cost. It may be true that this consumption for employees manifests CGN's human concern especially on its employees, but from a broader social perspective it is a privilege.

Mr. G's experiences correspond to the CGN's changes. Professionally, he changed from a design engineer under the framework of a licensed duplication to an experienced professional of reverse engineering. In these transitions, Mr. G caught up with the opportunities the company could provide. As CGN is now dedicated to a more in-depth research and development project, which aims to construct a Gen-3 nuclear power plant with complete intellectual property, on the contrary, Mr. G is getting further from this type of engineering practices with his useful knowledge. Is it going to be a missed opportunity for him?

Mr. G has no other career experiences other than his employment in CGN. Therefore, his transition represents a typical model for CGN's engineering designers. However, CGN engineers are quite diversified. That indicates the human side of engineering in this company may have other interpretations.

5.2. STRUCTURE DESIGN ENGINEERS – MRS. S AND MR. L

5.2.1. THE DIFFERENCES BETWEEN SYSTEM AND STRUCTURE DESIGNS

Nuclear power engineering is an assembly of serval engineering disciplines, mechanical engineering, civil engineering, process control, etc. all included. Due to the difference of the object of design, engineering designers have different understandings of their tasks.

Mr. L – one of our main equipment designer – described his perception of his work as such:

> "For me, designs can be classified into several categories. First the R&D related jobs, such as the design tasks in the ACPR 1000 (now HL1000) project. In detail, we get some input and based on our scope of work, we work out some calculations, and perform some verification. In the end we lead to some conclusions and these conclusions serve as the input for follow up engineering disciplines. Or the conclusions may support the next phase of our own design such as the detailed design, in terms of making manufacturing drawings and assembly drawings." (Appendix, D)
>
> "The second part of our job is to support manufacturing factories, in case the manufacturer raises some questions which require further interpretation. Some questions derive from the misunderstandings of our drawings and some from the non-conformance reports (NCR) discovered by our surveillance people. NCR refers to the inconsistency of the manufacturing with the design documents; it normally represents a manufacturing problem but not a fatal mistake. Testing and evaluation are required by the designer to decide whether this non-conformance can be accepted according to the technical standard and the functional requirements." (Appendix, D)
>
> "The third part of the technical work refers to some supporting work to the site problems which happen in erection and installation. Some equipment may be scratched during such activities. Therefore we need to send our engineers to the site to evaluate whether such slight damage would impair the function of this mechanical part, and do some testing on whether it causes risks to its duration etc." (Appendix, D)

Mrs. S – one of our civil engineering designers – described her design tasks as such:

> "I make plans and blueprints for the building structures, and verify their validity. Based on the comments from other disciplines – my colleagues

> – I need to make modifications on my plans and blueprints. These are what I call the technical tasks. I calculate based on numerical analysis; I issue drawings and reports. These tasks directly reflect my own perceptions on engineering design.” (Appendix, E)

The major difference between Mr. L and Mrs. S’s perceptions of engineering design and Mr. G’s illustration of his tasks is that both Mr. L and Mrs. S consider their designs as an engineering blueprint making for a specific object – a building or a machine – rather than a process.

This deviance from the system designer’s perception can be reflected from their descriptions of a nuclear power plant as a system.

> Mr. L said: “The nuclear power plant system consists of its sub-systems, we call units. Every unit has to perform its functions so that the entity can be made. The entity is the system.” (Appendix, D)

When Mrs. S was asked about how much she knew about the nuclear power plant system, she replied:

> “I kind of know something about the nuclear power plant system. But I certainly don’t know all.” Later she acknowledged the relationship of her work to her colleagues’. As she put it: “Not exactly, we need to know some basic parameters of the system for example the seismic classification of equipment. And we also have to know some data from the operational conditions. We need to perform our calculation and simulation according to the definition of accidents, such as the basic design accidents, or severe accidents etc. We have to get a feeling of what is a normal accident and what is a vital accident. Technical standards used in the design of the structure vary upon these conditions. However, the design for a nuclear power plant can be referenced to some normal civil engineering standards. In nuclear power plant design, we need to know the calculation methods stipulated in the technical standard for different accidents, and the verification methods. Otherwise, our calculation cannot be done.” (Appendix, E)

5.2.2. THE IMPORTANCE OF EXPERIENCE AND DETAILS

Even though both mechanical engineering and civil engineering have been established engineering disciplines from the scientific paradigm of physics, Mr. L and Mrs. S seemed to hold different criterions on defining what a good engineering design is.

Mr. L gave his criterion as the following:

> "In my view, our job is to design good products, in terms of good seismic resistance feature, and long term duration in operational circumstances. Therefore, we focus on the materials, and their mechanical properties and their fatigue analysis. In order to ensure the stability and completeness of the equipment we focus on the structural effects of our machines. We cannot make mistakes because if our products fail, it will have a big problem. Unlike the system designers and the safety analysis people who calculate safety risks on a probability study, we cannot rely on probability study. So risk does not mean anything to us. Our job is to make sure that our products will still be able to function even in the most severe accidents." (Appendix, D)

Mrs. S does not deny the essence of civil engineering design is to construct an endurable building which is a foremost requirement of nuclear power technology. As she put it:

> "The essence is the analysis of the load-carrying capability, and the properties of the materials, the concrete and the steel. When we figure out the stress and load distribution of the structure, we can work it out. Force and the properties of materials are the essential elements of design." (Appendix, E)

But in addition to this scientific perception on a good civil engineering design, Mrs. S emphasizes the importance of experience which is missing in Mr. L's expressions.

In order for me to understand how a designer's experience influences the quality of the design work, Mrs. S provided two examples. The first example was a problem of sizing:

> "This problem derives from the so called 'habits' of our design. Normally the sizing of the holes on the floor plates is regular in our previous designs. It depends on the sizing of the bolt which would be fastened into the hole in order to sustain the weight of a pipe and the cables inside it. No one has questioned the sizing and its impact on the load carrying capacity on the floor slab. Because we know the sizing of the holes is small so that it won't bring about a problem. But this time we intend to put more cables inside the pipe thus the hole is required to be larger, and now someone raises the question on the load carrying capacity issue, whether such a larger sizing of the hole will impact on the stability of the floor slab. If we have not calculated the case of large sizing, we need to start the calculation from the beginning, which is a time consuming job for this tiny problem. But if someone have the experience, the decision is easier to be made." (Appendix, E)

Another example she used to make her argument was about a mistake happened in the reading of the civil engineering shop drawings. In the Taishan project, on the steel structure detailed design drawings some oval circles were presented. Such oval markings are intended to tell the constructor to make exactly oval holes on the steel beam. When these holes are filled with bolts, the stress of such connections can be released. But what happened on Taishan site was that in one set of the steel structure, all the holes were made into perfect round holes, thus the stress of the beams and the bolts could not be released as it was intended. The constructor said that they misunderstood the oval drawing to the tolerance of the round shape. Since they can make perfect round holes, such oval shapes on the drawings are disregarded. In fact, if some words can be added to the oval circles on the drawings, such a mistake of the contractor can be avoided. Unfortunately there were no such illustrations on the drawings indicating that the holes shall be made intentionally oval but not tolerances. Mrs. S said:

> "Experienced designers would add words on because they must have experienced similar events. But it is hard to say if it is a mistake of the designer or not."(Appendix, E)

As a summary of her points about experience Mr.S concluded:

> "Experience comes from details. Knowing the scientific principles and the knowledge do not equal to a good design. A good design comes from practices and the learnings from mistakes." (Appendix, E)

5.2.3. PERSONAL BACKGROUNDS AND THE PERCEPTIONS OF GOOD DESIGNS

Such a difference on the interpretations of a good design partly derives from the disciplinary features of Mr. L and Mrs. S. As a mechanic engineer Mr. L focuses on the follow-up manufacturing process, in which the making of machines – his designed objects – is largely done by other types of automatic machines. While Mrs. S's blueprints are implemented by human workers on site. In the comparison of turning their designs into real life material structures, more human factors shall be counted in Mrs. S's designs. It looks as if the shaping of Mr. L's designs into reality requires only sequenced steps of physical and geometric transformations. Nevertheless, looking into the different career development backgrounds, the emergence of such a different evaluation of a good engineering design may have other interpretations.

Mrs. S is a 45 years old female civil engineering structure engineer. She was educated in the Southeast University in Nanjing China. Her university is one of the recognized good universities of engineering especially in architecture and civil engineering. She was educated to the bachelor's level. She had 22 years of working experience always in civil engineering design. At the beginning she worked in her home town after her graduation from the Southeast University in a mineral mining engineering design institute for seven years in a northern province. It was in the late 1990s and early 2000s. She thought southern China would provide her with more promising career development opportunities. She decided to move to Shenzhen with her husband a mechanical engineer also a graduate from Southeast University. She joined ARUP – an internationally well-known civil engineering design and consultancy firm – in its greater China branch in Shenzhen. She mainly worked on normal civil engineering projects before she switched to CNPDC in 2008 when CNPDC started to form its civil engineering design division. She was directly employed by CNPDC as a specialist in civil engineering design.

In this respect, focusing on the object of design, Mrs. S experienced two major changes: her first change was achieved by switching from a mining and mineral production factory building design to a commercial and resident building design. The latter, in her perception, contains more technical contents because these commercial buildings are structurally more complicated. The second transformation she experienced was to change from a commercial building designer to a nuclear power plant building designer. The design of the nuclear power plant building is, in her words, "more specialized" especially on its anti-seismic calculations. Putting Mrs. S's changes into a broader social context, her career success is largely a personal reflection on China's economic reform of which the direction has become clear since the 1990s. Her second change can be characterized as benefited from the renaissance of nuclear power in China, which can be regarded as a part of China's on-going economic structural change or technological upgrade.

I became familiar with Mrs. S in late 2009 when I was asked to be involved in the negotiation of a smaller joint design project between CNPDC's civil engineering design division and IOSIS – A French civil engineering firm – which served also as a sub-supplier of AREVA NP for the Taishan project. It was an additional self-reliance project on civil engineering design which could not be included in the NITT contract because AREVA NP, without enough competence of civil engineering design, had to sub-contract this part of nuclear power plant building design to a specialized company IOSIS. Mrs. S served as the technical leader in this joint design team. It was in the occasion that I was given the opportunity to have a closer observation of the real life working scenes in CNPDC. I even had a temporary small office beside Mrs. S's office as the commercial engineer for the operation of this joint design team. What I witnessed most was their corrective modifications on the drawings issued. Some of these necessary changes were caused by up-stream input changes, for example if a piping designer changed his or her choice of pipes to be used on site, then the civil engineers had to make a change on the illustration of their shop-drawings, sizing or the route of the pipes. Some of these changes had to be adapted according to the feedbacks of the site construction workers. Because designers did their jobs on systematic imaginations but sometimes these imaginations conflicted with each other in reality. For instance, when the constructors were ready to install a pipe on the wall, they found that another pipe had already existed at the same position with a different color. In such a circumstance they had to stop and wait for the explanation given by the designer. Either it was a mistake of illustrating the same pipe with two colors or it was a mistake by marking two pipes at the same position. It gave me a feeling that engineering design, as Bucciarelli (1996) portrayed, was a highly iterative process and the idealized systematic design process was just a logical sequence of engineering activities.

Mr. L is a young man who was educated to be a mechanical engineer in the university. He was employed by CGN in the year 2007 when he was just graduated from Xi'an Jiaotong University with a bachelor's degree. Now he was taking a part-time study in mechanical engineering to promote his education to the master's level. Mr. L's first job was in Shanghai, in one of CNPDC's subsidiaries. Then he moved from Shanghai to Shenzhen. I got to know him in 2009 when he was appointed a desk job reviewing thousands of technical documents transferred under the NITT contract – the technology transfer contract between AREVA NP and CGN on the EPR technology – on main equipment designs. His task was to reply to me what he found missing in these seemingly numerous documents. The manufacturing of even a single piece of equipment requires a set of documents which include its heat treatment, crack detection, welding, etc. The issuance of these documents in the Chinese technical system belongs to the responsibility of the designer instead of the manufacturer. In this respect, Mr. L was the designer to make sure its completeness. Therefore, he thinks like a manufacturer.

5.2.4. A DIFFERENT APPROACH OF LEARNING FROM AREVA

Compared to Mr. G, Mr. L was not given an opportunity to participate in the JDO. In this regard, his approach of improving engineering design, at least from a technology transfer point of view, is learning through reading. Later Mr. L was given an opportunity to review AP1000 main equipment design documents because CGN joined the AP1000 technology transfer. Both these desk jobs gave Mr. L a chance to compare the EPR and the AP1000 equipment designs. When I interviewed Mr. L he made his comments as the following:

> "I think EPR has a better reactor vessel. AP1000's reactor vessel is rather old. AP1000 may be advanced in its safety systems but when we look at the design of the reactor vessel it has nothing radically innovative. What I can say here is that the EPR reactor vessel has solved more mechanical problems in its design than the AP1000." (Appendix, D)

At this point of the interview, I considered Mr. L as another typical young man admiring for advanced technology. Thus his perception of improving engineering design might be similar to Mr. G's in the sense that getting more knowledge served as his point of departure. But his reflections on this topic were beyond my conjectures.

> "I don't think the rotation of jobs is going to be helpful for engineering design capacity building. Capacity building needs to have a purpose. If after a round of rotation I am still appointed as the equipment designer, I will think it is a waste of my time. Because, the system knowledge only serves as the background of our design, we can learn it by ourselves. We don't need in-depth knowledge of the system unless we find understanding the input data difficult. I think it is better to have a narrow split of work in our company so that people can focus. The methods and tools used in other disciplines can be very different. In equipment design we don't need their methods and tools." (Appendix, D)

Compared to Mr. G and Mrs. S who possess a relatively collective understanding on this issue, Mr. L holds an egocentric stance. On one hand, he relates the improvement of engineering design directly to himself as a personal promotion of skills and knowledge. On the other hand, he seems to be satisfied with the fulfillment of his own job and at the same time remains careless about his colleagues. It is only in the situation that he finds a lack of information or an insufficient understanding of data that may lead to his personal failure, communication among engineers and cross engineering disciplines shall take place. Provided that Mrs. S's purpose of improving civil engineering design is in some sense altruistic, and Mr. G's goal approach of improving system design through accumulation of knowledge seems neutral, Mr. L's self-strengthening approach is straightforwardly egocentric.

5.2.5. MR. L A FOLLOWER OF MR. G

It looks as if the rising curve of Mr. L's career development can only be manifested by his promotions under the established models of his predecessors such as Mr. G. Another reason for the egocentric recognition on Mr. L is that he thinks – at least he said – that his promotion and his good performances are almost a result of his own endeavors instead of a collective achievement.

> "The promotion to the group leader is a surprise for me. Because at the time when I was promoted, I had only been working in CNPDC for 3 years. Normally, in our division the promotion to a group leader is based on the following criterions: Experience, in terms of how many years the person has been working in CNPDC, and education background (major and degree). If these criterions were constant I would never be chosen.

> My advantage is that every time when I receive a task, I try to think about the expectations of my superior. And he once told me that every time when I accomplished the work, in most cases, the result was beyond his expectations." (Appendix, D)

Mr. L may not be a socialized person or in his mind social connections in an engineering company like ours can be simplified as competitions. Therefore, knowledge and skills become important resources and instruments of gaining personal comparative advantage. This understanding of the social relationships inside a company as competition may be an analogy of the marketing competitions among companies, such as his comparative evaluation on the reactor vessels of the EPR and the AP1000 technologies.

5.2.6. THE ANSWERS TO WHAT'S WRONG IN CGN BY MRS. S

In Mr. L's perceptions of engineering design, his work consists of a series of daily routines: getting orders from his superiors, attending meetings to gather information, splitting work tasks among his group members, reviewing mechanical drawings, answering questions etc. Nothing seems to distract him from constructing mechanical structures in his own mind. Communication for him only happens when he finds it necessary. He does not perceive it as a burden because it is not important in his work. But Mrs. S holds a different opinion on this matter. She said:

> "Now my days are filled up with different technical tasks for different on-going projects, some R&D projects, and some specific meetings such as the quality assurance meetings etc. The situation that one engineer participates in two or three tasks at the same time is quite normal. In general too many meetings take up my hours. These meetings can be classified into technical meetings with related disciplines, progress report meetings to my superiors – to the divisions – and to the project organizations etc." (Appendix, E)

> "Another part of my job is to reply emails and writing reports. I feel that most of my time is used on either attending some meetings, or preparing for those meetings. As far as I know, a lot of our engineers live and work like this." (Appendix, E)

> "I think it is a feature of nuclear power engineering, because it involves too many people and too many disciplines for just one purpose. For normal civil engineering projects, less engineering disciplines are required. There is a huge cost of communication induced by such a huge number of interfaces. This is a typical feature of nuclear power engineering." (Appendix, E)

Mrs. S felt exhausted about multiple reporting and attending numerous meetings which might indicate that they were time consuming. In fact she criticized the efficiency of these types of communications instead of their necessity. According to her, meetings should be effective in terms of making decisions otherwise resources spent on them are wasted. This was especially the case during the year from 2008 to 2013 when CNPDC's offices were dispersed in four locations in Shenzhen City. It was the years before CNPDC's office building were finally built for its nearly 2000 employees. But even now CNPEC and CNPDC possessed different office buildings about 30 kilometers away from each other. Routine shuttle buses connecting these office sites had to be set up for the purpose of human and material – largely documents – transmissions.

Another implication can be elicited from Mrs. S's expression is that interfaces among engineering disciplines can be problematic. Engineers in CGN prefer clearly defined interfaces. One approach of the establishment of a clear-cut interface is to split a seemingly consummate interface into specific smaller parts, as specific as possible. This may not increase the total number of interfaces among engineering disciplines in general but will certainly increase interfaces at the personal level because engineers are the ones who perform specific tasks, and they are supposed to contact with those who raise specific questions. In such a situation the number of people attending a technical meeting can be numerous. Provided that each person is given a chance to speak, it is very likely that the meeting is going to be prolonged. But the critical problem is "Who is going to make a decision when all the participants seem to make sense?" (Appendix, E) A typical CGN approach of solving this problem is to raise such discussions up to a higher level meeting, such as a meeting among chief engineers. But before that, these unsolved questions have to be reported to that level by issuing a minute of meeting or a report.

Mrs. S's words reminded me of a joke which Mr. G told me about the interfaces of nuclear power engineering design. He once said that building a toilet in the main control room inside the nuclear island required the participation of 20 different engineering disciplines in CNPDC: air condition and ventilation, electrical engineering, fire prevention, water utilities, etc. He may exaggerate the facts but it reveals some facts.

5.2.7. THE PROBLEM OF INTERFACE IS A COMMON PHENOMENON

I am not trying to say that the problem about interfaces is a question with CGN characteristics only. It seemed to be an international problem experienced by nuclear power engineering companies. As Mr. M from AREVA NP put it:

> "Corporation between the interfaces is very complicated in this sort of 'real' design. The corporation between the disciplines will experience a process first at the general level then into the details." (Appendix, C)

Mr. M acknowledged the importance of communication between engineering disciplines via interfaces, but later he turned to express his critical view on AREVA NP's real-life operations on the interfaces in the Taishan project's engineering design.

> "When we were doing Daya Bay and Ling Ao, all the people were working in the same tower, the AREVA Tower, including Sofinel (AREVA's Design Institute). So it was easy to communicate; now it is too scattered. We have people working in Germany, and people in France, and even in France we had many offices. Sofinel is not in Paris. Can you imagine?" (Appendix, C)

> "And the split of work, who is in charge of this and that, when you do it like that you multiply interfaces by 10 by 100. If you cannot manage the interfaces you will fail. You will be in delay. From my own experience, for me, but it is off-record, the delay of the EPR is the result of the interfaces. Too many people working together, and too much split of the work. There is a lack of organization and procedure of how things to be done. That is my personal feeling. That is why for the management, a good organization should have sound basic procedures. If you solve these fundamental topics you will be able to succeed." (Appendix, C)

In many ways CGN is mimicking AREVA NP and such an attempt has long been permeated into various aspects of CGN's engineering practices including its engineers' languages. The most evident example can be given by the Latinized abbreviations of CNPEC's second level organizational acronyms. CNPDC which is in fact a CNPEC's subsidiary is abbreviated to EDE (Engineering Design Entity). The word entity which is to some extent foreign in the Chinese habit of using English is equivalent to the French word entité which sounds almost the same for a Chinese who has learned some English. Even though the English word entity might not derive from a French origin but certainly French people are using entité in their expressions of company organizations at least I once heard of it given by my counterparts in AREVA NP. It seems to me that CGN engineers through their long term communications with the French partners have just borrowed this semi-English and French – in this case – expression to our own language.

CNPDC is called as she ji zhong xin or she ji yuan which can be literally translated into English as Engineering Design Center or Institute, instead of its official name as China Nuclear Power Design Company in CGN engineers' everyday language. I find that in English center and entity emphasize slightly different meanings when they are used to express organizational structures. According to the Merriam-

Webster Dictionary of English entity means “an organization (as a business or governmental unit) that has an identity separated from those of its members”. (Merriam-Webster Dictionary1 Accessed December 24, 2014) Center can be interpreted as “a facility providing a place for a particular activity or service”, “a region of concentrated population” or “a source from which something originates” (Merriam-Webster Dictionary2 Accessed December 24, 2014) when it is used to illustrate organizational concepts. From these linguistic definitions, it is evident that entity emphasizes different functional identity of an organization among other parts, while center addresses a sense of assembly or synthesis which focuses on central control or uniformity. In this respect, the choice of the word entity in CNPDC’s acronym is a deviation from its Chinese original concepts or intentions.

When French engineers say entity they may naturally be aware of its precise meaning from their own cultural and language backgrounds, but when Chinese engineers appropriate this word, I am not sure whether they have noticed the difference between the meanings they have chosen and how far the expression deviates from their original Chinese perceptions. I am not trying to be captious on Chinese engineers’ proficiency in English language because it might just doesn’t matter taking into the consideration that improving engineering design is to a great extent a technical matter. Nor, I tend to ascribe this language phenomenon to the difference of Chinese and Western cultural traditions. What I want to indicate through this seemingly irrelevant example is that learning from the West can have more profound meanings which simply a metaphor as borrowing or appropriating may not be enough to interpret. Anyway, it seems that both Chinese and French engineers prefer simplicity and that is the reason why the Taishan engineering flow chart was expressed by numerous acronyms.

Learning from AREVA may indicate that CGN encounters the same questions which AREVA has experienced. The dilemma of engineering interfaces serves as an example of this kind which means when CGN represents its contemporary version of learning from the West with some substantial contents, some critical reviews of AREVA’s experiences are necessary. But unfortunately, I would consider that such critical reviews lacked.

5.2.8. PROFESSIONALIZED ENVIRONMENTAL CONCERNS

Mr. L is an active participant in CNPEC’s 3D printing technology study group. It is a spare-time voluntary internet forum – a loose network – established by CNPEC engineers. According to Mr. L, 3D printing technology has now been utilized in mechanical industry for serval years, and probably one day it will be used for nuclear power plant’s main equipment manufacturing. Therefore, his participation in the voluntary learning of this technology fits into his engineering discipline and in addition, it represents his environmental concerns. He considers 3D printing a new approach of achieving lean production which will have a potential of dramatically reducing material consumptions in machine making. The most direct supporting example he gave was that 3D printing would make the molding of a structurally complicated die much easier. Promoting efficiency and avoiding waste have become his perception of environmental protection. Importantly, this kind of environmental concerns are what he thinks to be achievable by mechanical engineers in China.

Mrs. S's environmental consciousness seems to be more diversified. She mentioned some of her previous jobs which could be regarded as making energy saving buildings. In detail, she referred to her choices of using energy saving building materials. But in CNPDC she acknowledges that using energy saving materials is completely not a concern in nuclear power plant's building design. What is treated to be important in CNPDC is to make anti-seismic structures and to choose the materials which can prevent radioactive rays from penetrating. Ironically, this can also be interpreted as a form of practical environmental consciousness which is shared by all CGN engineers – in our own terms a nuclear safety culture. Aesthetical values are not her concerns because they belong to the concerns of architects who are professionally regarded as another engineering discipline in China.

5.3. COMMERCIAL ENGINEERS – MR. W AND MR. F

5.3.1. THE EXISTENCE OF COMMERCIAL ENGINEERS

System design and structural design engineers seem to live and work in their own worlds. Communications between them and the outside world in terms of their physical models, calculations, and rational reasoning – their paradigms – can be summarized as a form of information exchange. In CGN, I would rather say that even this form of external communication is not performed in a direct manner. There is a type of engineers who served as the mediators between the engineering object worlds and the outside social world. They are not direct participants in engineering design in the sense that they don't issue drawings and calculation reports. But they cannot be exempted from engineering design because their influences and involvements cover the entire life-span of the projects. Going down stream of a normal engineering sequence it is through them the purchasing orders of containers, machines, cables, pipes, pumps etc. are contracted to CNPEC's sub-suppliers based on CGN's designs. It is also through them building designs are transformed to construction and installation activities. From an economic perspective, it is through them design engineers' work is translated into monetary terms, as men-hour inputs, and consequently the values of knowledge become visible. Going up stream, before the kick-off, it is through these engineers the Environmental Impact Assessment (EIA), which is required by the NNSA to be included in the project's feasibility study, is performed and submitted to the concerned governmental bodies. At the time of completion, it is also through them the final safety analysis report (FSAR) is liaised with the NNSA, and finally a permission of fuel loading which is in fact the most important license leading to commercial operation, is granted. In a summary, they are the ones who control and monitor the progress of the project.

These commercial engineers can easily be distinguished from still other types of CGN employees such as the administrative staff specifically a human resource manager for example. Commercial engineers are project based but those who performed general tasks are not positioned in a specific project organization. Compared to these administrative employees, commercial engineers are more intimate to CGN's engineering practices. From a managerial perspective these engineers are normally placed in CNPEC's Project Management Entity (PME) and Planning and Business Entity (PBE).

Despite of these commercial engineers' organizational differences like those of design engineers permanently employed in different divisions, they are all put into a virtual project office. This virtual office is called a project management office under the leadership of a general project manager. The split of work inside such a project office is defined by the 9 areas of controls in the modern project management knowledge system. (PMBOK 2008) The general project manager and his or her deputies are in charge of the overall control responsibility of the nuclear power plant project. The control of the scope of work is attributed to the contract engineers – drafting, interpreting, and modifying contracts when necessary. Scheduling control engineers are those who perform the monitoring of the progresses. Budget control engineers are mainly those who deal with financial matters. Quality control and assurance engineers make sure the quality of the procured goods, the engineering practices of the designers and other service providers to comply with the ISO9000 standard and those additional requirements set by NNSA such as the HAF codes (Chinese Nuclear Safety Regulations). In each project management office there is a document control group, in which communication channels and routines are set up. This group delivers the right document to the right people and sends reports to the correct level of CNPEC's higher management above the project office. There should be a risk management engineer who collects various data and performs some analysis in order to find abnormal incidents that may cause a delay or budget over-run which are regarded as the major risks to the project. Procurement engineers inside the office take the responsibility to outsource the goods and services that cannot be generated within CNPEC but are essential to the completion of the project, such as the sub-contracting of the manufacturing of the main equipment – the reactor vessel – to qualified sub-suppliers. At this point 8 types of jobs have been addressed except a human resource manager position which normally should be included in a standard project management office as it is suggested by the PMBOK. However, it is not the case in CNPEC.

The task of predicting and distributing man-power is left for the administrators at the company level, and at the same time, the general project manager possesses some power in human resource issues which are directly reflected by his authorization to decide which person should be appointed on which position inside the project management office.

What is common among these seemingly separated and diffused tasks is a unified procedure out of which the work is done in CNPEC. All these tasks start with a kick-off, and then turned into their planning phase. After their implementations along with a series of monitoring and corrective activities; the closures can finally be achieved. (PMBOK 2008) This common procedure has three aspects of implications. First, compared to the more traditional engineering disciplines, scientific management has set up its own discipline in CNPEC. It looks as if scientific management has constructed its own object world. Second, from a methodological point of view, it made an analogy of project management to other types of engineering work especially to engineering design. That is to say, project management can also be perceived as a sort of design job by perceiving both of them as decision making. If this perception is true, then what is the object of this type of design? This leads to the third implication of this discipline that indicates social relationships can be treated as objects of design.

In general CNPEC engineers' external communications with the society are achieved by their commercial engineers. Precisely from a disciplinary perspective, these engineers can be named as project management engineers. But I think that such a name does not reflect the essence of them. In CGN, it is through these engineers technology has been transformed into commodities. Therefore, perhaps calling them commercial engineers is more appropriate in contrast to those technical engineers.

5.3.2. EDUCATIONAL BACKGROUNDS OF COMMERCIAL ENGINEERS

Unlike the system and structural designers who have to be educated in already established engineering disciplines, commercial engineers in CGN come from a varieties of backgrounds. It is quite often that licensed lawyers serve as the contract engineers. Statisticians are hired to perform project scheduling tasks. Librarians are turned into document managers. However, what appears more often is that the technically trained engineers are turned into quality control and assurance officers, procurement engineers, and even budget control managers. It means that, in CGN, switching from a technical discipline to another less technically loaded job is an easier case than its reverse direction because science and technology is considered as more privileged knowledge.

In order to illustrate our commercial engineers' experiences, two individuals were interviewed. One of them is a thermal power engineering trained procurement engineer and the other is a contract engineer with a business administration degree.

Mr. W is now a 37 year old procurement manager in the Taishan project. His bachelor's education was received from an engineering college specialized in the training of electrical power engineers in northern China not far from his hometown. He was born into an engineering family. His father is now a retired thermal power engineer. In this respect he inherits his father's engineering profession. Due to his father's connections with the industry, Mr. W got a job in the same company in which his father had worked for decades as a conventional coal power plant installation and commissioning engineer after his graduation from that engineering college. Two year after his working in that company, with a hope of bringing some changes to his life, Mr. W decided to study in a master's program in a more prestigious university in Guangzhou, the South China's University of Technology. It might be true that Mr. W experienced some culture shocks as a migrant from the northern part of this country to its southern part. What unchanged was his engineering discipline in his postgraduate education.

With a Master's degree, he was given an opportunity to work in a power plant engineering science and technology research and development institute in Guangzhou. It was a better company but the job did not last long. Not in a year he decided to join CGN which he thought might bring him a brighter future, because in the research and development institute his Master's degree compared to a PhD degree was considered less competitive. His first job in CGN started in 2005. It was a position located on Yangjiang site, because he was recruited as a system testing and commissioning engineer. At that time the Yangjiang CPR1000 project was still in its feasibility study phase in the sense that the authorization to proceed (ATP) had not yet been issued by the NNSA. Therefore, precisely, he served as a commissioning engineer in waiting. The major task he performed in that period of time was to study the previously used engineering documents of the already completed projects such as the Daya Bay project and the Ling Ao Phase 1 project. CGN was quite optimistic, in 2005, in getting the Yangjiang project's ATP because it was the time when the Ling Ao Phase 2 project was just started that symbolized the renaissance of China's nuclear power.

His opportunity of transforming into a commercial engineer appeared in 2006 when CGN tapped into a negotiation with AREVA NP on the construction of two EPR units on Taishan site. Compared to the CPR1000 technology, the EPR seemed to be more advanced Western technology, and this indicated that from a human resource perspective, people involved in this project should be those with some fresh knowledge and well prepared. That was the reason why Mr. W was chosen. With some knowledge reserves of knowing the nuclear power plant's system and some sense of knowing how a nuclear power plant could be built from his studies on previous documents, he was appointed a position as the scheduling control engineer in the negotiation team. Joining the team brought Mr. W to Shenzhen.

The abovementioned interviewees are engineers with engineering education backgrounds. Mr. F is a commercial engineer in CGN without an engineering higher education. To some extent, he is not a school trained but a self-trained engineer. His knowledge about engineering was largely gained from his work in CGN and in his previous experience in IBM.

Mr. F is now a 36 year old man who has been working in CGN for more than 8 years. He is a second generation migrant from northern China to Shenzhen. His family moved to Shenzhen, China's first special economic zone, in the early 1980s before Mr. F was old enough to receive his 9 years compulsory education. His primary and secondary school education was received in Shenzhen. Unlike most of the CGN engineers who spent their high school years in science streamed classes, Mr. F was an art streamed student in high school. His choice in high school led him into a foreign language and business studies university in Guangzhou to complete his higher education. After his graduation from Guangdong University of Foreign Studies, he went to the University of Surrey in the United Kingdom for his postgraduate education. He came back to Shenzhen with a Master's degree in international business management in 2004 and soon after his return he was employed by IBM.

Working for a multinational company was still a fashion among the young Chinese educated people in the early 2000, but Mr. F was unsatisfied with his job in this famous company. On one hand, his job in IBM was largely clerical. Specifically it was a customer service job, in which Mr. F was in charge of answering his clients' questions on a webpage. Therefore, he considered himself as an answering machine. Without a promising career development path, Mr. F considered it not a decent career. On the other hand, unlike CGN which was and still is trying to provide to its employees an internationally standard salary, IBM was paying according to its perception of the localized standard. Knowing how an IBM employee was paid in the UK, for example, Mr. F felt that he was treated unfairly in this international company in China.

CGN has been established in Shenzhen for almost 3 decades. Its headquarter, CGN tower, the science and technology building shared by CGN with the city's Intellectual Property Office, a governmental agency, situates in the central business district of this city. This location can easily trigger a high-tech image on this company. In addition, CGN's shuttle buses connecting its dispersed offices and its nuclear power plants' sties serve as a good media for advertisement. Running though the city with a CGN logo, the buses give the commoners an impression that CGN is a financially affluent company, in the sense that its employees' transportations are provided on a free of charge basis. In Mr. F's case, this advertisement worked, because it gave him a guarantee that his benefits can be ensured as long as he got recruited. It was in 2006 Mr. F joined CGN.

5.3.3. WHAT DO COMMERCIAL ENGINEERS DO?

By the end of 2007 when CGN and AREVA NP finally entered into the contract on the construction of the Taishan EPR unit 1 and 2, which implied that the issuance of an ATP was just a matter of time, Mr. W received his new assignment. A consortium consisting AREVA NP as the leader and CNPEC and CNPDC as AREVA NP's sub-suppliers was formed to serve as the lump sum supplier to the owner. Due to the fact that the work for CNPEC was delineated within the balance of the nuclear island (BNI) – not the complete scope – the overall scheduling work had to be led by AREVA NP. Therefore, Mr. W was given a task on the scheduling control of the procurement activities within CNPEC's scope of supply. This assignment was later extended to an overall project management task which included not only scheduling control but also coordination with CNPDC and AREVA NP representing CNPEC.

The extension of his job, from my perspective, was inevitable taking into the consideration of the split of work within the consortium. Procurement engineers get their orders from the designers, because it is the designer who issues the technical specifications that stipulate what kind of equipment to procure. Even though, CNPDC is also involved in the design, it is only a service provider which cannot take the ultimate technical responsibility. AREVA NP who owns the technology's intellectual property right, is the ultimate legal person who should be subject to the nuclear liabilities of the plant's engineering design. That is to say CNPDC's design shall be logoed under the name of AREVA NP and from a practical perspective, all the documents used for procurement and construction must be approved by AREVA NP. In this respect, as a procurement manager in CNPEC for the Taishan project, coordination between AREVA NP and CNPDC is inevitable. Coordination of the procurement activities is not just a job of dealing with design matters. Almost all the 9 types of controls mentioned in the PMBOK (2008) are relevant.

Mr. W is a busy person. He travels a lot to different equipment manufacturers both domestically and abroad. When a non-conformance of manufacturing related to the CNPEC's scope of supply is reported he is the first one to know. Then he has to clarify the situation with the designers in CNPDC or in AREVA NP. Since AREVA NP is entitled to issue design modifications or variations as long as it finds necessary, such orders have to be transmitted to the manufacturer from Mr. W. Normally, modifications are accompanied with financial issues because they represent extra work. In real life, not all these tasks are done by Mr. W alone, but he plays an important part. There are about 30 to 50 engineers working under him depending on the different phases of the engineering design. Internal meetings with designers and other types of commercial engineers take up a majority of Mr. W's daily routines.

Mr. F's first job in CGN which lasted for about 8 years was to act as a contract engineer in charge of purchasing technical assistances and supporting services from prominent foreign nuclear power engineering companies in case CGN met technical problems that it cannot solve or required some third party review of its technical documents. The nature of Mr. F's job did not change too much over the years but his contacts covered a wide range of people including engineers in CGN and the business persons in his suppliers. Similar to his jobs in the IBM, he kept on sourcing services, but for CGN he had to source outside in the market. By treating CGN's design engineers as his clients, Mr. F was given an opportunity to learn more concrete technical contents which he thought appreciated his professional status.

> "Since I joined CGN in 2006 my job has always been related to our engineering design. But it doesn't mean that I personally perform engineering design. I have always been playing a supportive role to our designers. I am a contract engineer dedicated to technical assistance contracts. That is to say, I purchase supporting services and documents from prominent foreign nuclear power engineering companies to help our designers to solve problems or review their work. Previously our design could be described as duplications plus modifications; therefore we need numerous references. In this respect, my job has been closely related to our design activities." (Appendix, G)

In 2014, in the aftermath of the Fukushima accident, when China temporarily suspended its ambitious nuclear power development in the domestic market and turned to be active in the international nuclear power market, Mr. F got his opportunity to take part in the planning of a nuclear power export project. CGN's attempts to export nuclear power plants derived from the country's confidence in the mastering of this technology which was reflected by its serval decades' successful construction and maintenance experiences. In addition, in recent years, perhaps China is the only country where both of the two well-known Gen-3 types of nuclear power plants (AP1000 and EPR) are under construction. Together with a consideration of upgrading China's exports of industrial goods and services to an advanced level, the central government encourages the export of nuclear power plants. The most evident government support for this exporting policy can be read from the news reports dated after 2013. In one of the Reuters' reports (2013-12-17) such a claim was formally addressed by Zhang Guobao, China's former top energy officer and a tireless promoter of nuclear energy. Mr. F is now a part of this attempt even though his role is minor.

> "Now I am in another oversea nuclear power engineering project, and still is a contract engineer. My job is still to support our design." (Appendix, G)

Perhaps the change from a contract engineer of purchasing technical services to a commercial engineer dedicated to a specific project pushes Mr. F further into the discipline of scientific management.

> "I am now a commercial manager for a big project even though it is still in its preliminary planning stage. I am involved in the project's licensing process. In this stage, I am also asked to source supporting services related to the modifications of the software we are using, the P6 system. It is the tool that we are using to manager our designs." (Appendix, G)

5.3.4. COMMERCIAL ENGINEERS' IDENTIFICATION OF THE PROBLEMS

Mr. W's work can be regarded as follow-ups of engineering design. His perceptions of engineering design focus on manufacturing. From his words the process of engineering design and the types of problem-solving included can be understood from a retrospective.

Mr. W distinguishes two types of engineers design in CGN:

> "In both system and equipment designs, the designers will raise some requirements on the specific equipment to be procured." (Appendix, F)

From his words we are able to deduce that engineering design is a form of decision making. Mr. W described this analogy of design to planning as the following:

> "The designers directly limit the choices of procurement and predict the range of the price we are going to pay for each piece of equipment. High demanding requirements indicate fewer potential suppliers. Therefore, the price is going to be higher. In some cases, the supplier will be required to carry out some R&D activities before manufacturing. This will cause some unexpected prolonging of manufacturing." (Appendix, F)

In this respect, a good design can be reflected by its accuracy of predicting follow-up activities and its compatibility to the established procedures and conditions – in this case technical standards. On the other side, engineering designers as good decision makers have to be equipped with an ability to deal with abnormal incidents which deviate from their plans and predictions.

These reflections about engineering design are shaped from his experience:

> "In real life work, we often witness some deviations from the design requirements, in the sense that the equipment on the market cannot meet the technical specifications of our design. In case such a deviation occurs, we need sound engineering design abilities so that we can find out how to deal with it." (Appendix, F)

> "Another aspect of engineering design capacity that I would like to point out here is the understanding of industrial standard. The major industrialized countries adopted different industrial standards. The Europeans use their standard. And even within Europe, the French adopts its own nuclear power industry standard RCCM while the Germans use their KTA. The good thing is that in Europe there is a general manufacturing standard. In China, we have the GB standard and the Americans have their ASME. In such a globalized and diversified situation, considering nuclear power engineering design and its follow-up procurement by competitive bidding, if the standard is chosen to be only one without alternatives, the choices for procurement become very limited. This will lead to a limited number of potential sub-suppliers from which we can finally choose one. A lot of bidders are rejected because they are not familiar with the required standard of manufacturing. If the designers can understand all these standards the situation will be better. Industrial standard for me is a set of rules and procedures. It does not directly relate to the quality and functionality of the product. But if the designer is not familiar with the standard, he or she cannot make a judgment on the product, and its impact to the system." (Appendix, F)

According to Mr. W nuclear power technology is not a high-tech. It has a matured industrial base. Therefore, too much R&D in the engineering design phase is not a positive factor for a smooth implementation of the project. He prefers definite and realistic plans or orders:

> "We are not really doing high-tech products; we are indeed in need of those already industrialized and standard products. You cannot make each piece of equipment used in the nuclear power plant a product out of a R&D process. This is not only true in our domestic market but also in the global market. If even the European advanced suppliers cannot provide ready products that meet the design requirement, I would say that the design is not good at all. In that case the designer totally disregards the reality. As a summary of this point, I would say that the designer must have enough information about manufacturing technics in the market. The design should not be a requirement that cannot be met." (Appendix, F)

But that is not to say that in normal designs when all the information is consummate, engineering design can be performed in a smooth progress without disturbances caused by iterations and deviations. In fact, verifications, reworks and tests which suspend or reverse the idealized process of a normal design are quite common. In CGN's engineering procedures all these abnormal incidents, especially those appear in equipment manufacturing, are recorded in a specific type of project reports called the Non-Conformance Reports (NCRs).

> "In our classification, NCRs are categorized into 3 types. The first type is called the I-category, internal NCRs. These NCRs are those incidents discovered by the manufacturers themselves. And these flaws can be mitigated or turned to normal by normal machine work, such as polishing a surface etc." (Appendix, F)

> "The second type is called the E1 NCRs, external category 1 NCRs. These NCRs mean that if they are mitigated, the functional requirements in the design can still be met." (Appendix, F)

> "E2 category NCRs mean that these flaws can never be mitigated. That is to say the owner of the plant has to accept the equipment with a compromise. But such a compromise shall also fulfill a set of prerequisites. First, the designer has to commit that the functional requirements in the design exceed the real operational conditions. Therefore, even with such flaws the design margin can still ensure operational safety. Second, through modifying other parts of the system or adjusting operational procedures, no incidents that may impair the intrinsic safety will occur. In any case, an acceptance with a compromise of the E2 NCRs means that the design requirements exceed the safety margin, therefore the equipment is still considered as workable." (Appendix, F)

Even though deviations may appear in different forms, their solutions can be categorized into two forms, specifically compromise and substitution:

> "One method often used is to make a technical compromise in terms of a substitution. Nuclear power plants are designed to work properly for 60 years but there is some equipment which cannot last that long, say 30 years, for example, according to our fatigue analysis some of the valves cannot reach to a service of 60 years. We have requirements not only for the valves' years of service but also their sizing and weight etc. In fact, to prolong the valve's service, the easiest approach is to make the shell thicker but this will increase its weight and larger its size. Due to the sizing and weight limits, some valves must be lighter or smaller. In this case a compromise is needed. With a thinner shell, the years of service

> can only be ensured, say 30 years. As a consequence, the designer has to consider its substitution in the in-service inspections. That is to say two values are needed to fulfill the plant's operation for 60 years. One new valve will replace the old 30 years after the plant's commercial operation. However, we must admit that there are always some problems which cannot be solved by this approach, in these situations the designer have to find other solutions." (Appendix, F)

> "Another kind of substitution happens when a different material can be chosen. But it is very difficult in our self-reliant manufacturing because using another material means to substitute an industrial standard." (Appendix, F)

In this respect, the more cases the designers have dealt with, the more capable of the designers to perform good engineering designs. According to Mr. W improving engineering design is a matter of accumulating experiences especially for our equipment design engineers.

> "I got a feeling that CGN engineers largely performed system design and lacked equipment design knowledge. The system designer focuses on flows and fluid mechanic. They seldom concern about structures, fatigues and materials. So from a CGN perspective, we need to nurture good equipment designers. On quick approach is to recruit designers with manufacturing experiences into CNPDC, or we need to tighten our corporation with our suppliers. As such the designers will get some first-hand senses on whether their requirements can be achieved in real life manufacturing. Now our designers do not have such senses, they often draft a plan first and then wait for manufacturers' feedbacks and corrections." (Appendix, F)

But getting knowledge is not equivalent to gaining experience because it requires a transformation of the theoretical knowledge to practical useful knowledge and that equals to project experience.

> "From a personal perspective, engineering design capacity building relies on experience. But experience cannot emerge just from book learning. Without verifications and tests from a real life project, knowledge seems to be useless. That is the reason why I consider engineering design capacity building as an organizational issue. Now, I feel that CNPDC's engineering design capacity is relatively theoretical in the sense that it is not competent in dealing with the problems emerging in real manufacturing processes. So engineering design capacity building can be considered as system engineering. If the company can provide enough projects, experiences of our design engineers can be generated from them." (Appendix, F)

It seems to me that Mr. W's perception of engineering design and the approach of improving it are systematic. What he favors is an idealized precise systematic production of documents and decisions which stipulate follow-up engineering activities. In order to reach precision, experience is needed, because experience can be useful in both predicting what will happen and finding out solutions in a timely manner. Such kind of systematic thinking reflects a constant pursuit of knowing the unknowns. Unknowns are considered as dangerous because they may lead to failures.

Unlike Mr. W, Mr. F's job is more remote to engineering design. However, Mr. F made his own analogies of his commercial job to engineering design and addressed the problems of engineering design and its solutions in a managerial tone. What seems to be evident from Mr. F's words is that his systematic thinking is no less heavy than his colleagues with scientific and technological educational backgrounds.

> Mr. F said: "We are exactly doing like this. For example the choices of our consortium members, or partners in the project, are in fact based on our data analysis on their competencies such as their revenues and profits. There are a lot of things that we consider from a quantitative perspective." (Appendix, G)

Despite of this similarity of his commercial work to engineering design, differences are also quite evident.

> "From my perspective the designers have to be precise, while for a negotiator, approximation and compromise are always needed for example the choice of governing laws for a contract. Each party favors that the contract shall be stipulated by the laws of its own country, but if everyone insists on their own wishes there will never be a contract. So the trade-off is to stipulate the contract on a third country's law. We encounter more social factors than the designers." (Appendix, G)

Both Mr. F and Mr. W emphasize the importance of precision in their understandings of engineering design. What differentiate Mr. F and Mr. W is that Mr. F thinks that only those social elements related to engineering design can be compromised. However, he does not know that in real life engineering design those hard scientific elements can also be compromised. This scientific impression on engineering design leads to Mr. F's perceptions on its management.

> "It is hard to say that which task can be solved solely by quantitative reasoning but, as far as I am concerned, commercial or planning jobs in CGN are relied on scientific management. For example our project management is founded on scientific management principles, the 9 areas

> of controls. Our company's management is constructed by its management systems, which are based on rational reasoning. So does the management of engineering design. It needs a system to organize our work so that it can operate smoothly. I think the engineering design management system shall be more rigid." (Appendix, G)

It seems that Mr. F and Mr. W meet the same conclusion on the function of the scientific management over engineering design. But it is important to clarify their different points of departure. Mr. W emphasizes the importance of scientific management in order to avoid deviations, but Mr. F thinks that since engineering design is a highly scientific job, it has to be ruled by scientific management and there is no other way to regulate these activities. In this respect, the natural and social divide in Mr. F's mind is quite obvious.

In CGN, Mr. F's perception on engineering design seems to be amateurish, and this impressionistic opinion about engineering design can also be reflected by his perception on the R&D activities.

> "I am questioning our approach of design. Because I feel that we are always performing a duplication of others' design with our limited modifications. The EPR and the AP1000 are not our products. Our real products are those modifications. In this respect, the HL 1000 may be considered as our product but certainly CPR1000 is not that kind of a product. At least in the development of the HL1000, we go through its R&D, not just duplications or modifications. We start from the origin. If engineering design is defined to be duplications and modifications, I tend to think that our designs are workable in a realistic sense taking into the consideration of scheduling. But I still think engineering design should be something more creative. The HL1000's R&D may be an example for that kind of engineering design." (Appendix, G)

Perhaps, it is due to his long term involvement in sourcing technical assistance to our design engineers, Mr. F's impression on good design focuses on the engineers' intellectual independence. In his perception, good work must first be original work. That is the reason why he also criticizes the daily routines of our engineering designers.

> "We need to reduce the waste of our energy in the interfaces. We need to reduce disputes over trifles among our departments and engineering disciplines. To do this a more scientific approach of management should be relied on. I hope under a better management scheme, engineers can focus, or spend more time, on real design activities or learning, rather than wasting their time on handling trivial things which are in fact not engineering design. However, I think improving our management can

> only serve a supportive role. The most important thing is that engineers spend more time on real engineering design. As such the result will be different." (Appendix, G)
>
> "Good management may stimulate creative thinking among our engineers. Just now I am trying to say that even though hard working is important, but it doesn't mean that creative thinking can be naturally generated through hard working. Creative thinking is important for a better design." (Appendix, G)

5.3.5. ATTITUDES TO NUCLEAR POWER AND TO ENVIRONMENTAL ACTIVISM

Although Mr. W does not deny the lurking environmental risks regarding to nuclear power technology, he points out that there must be a solution to this problem. When I discussed with him during a lunch time about He Zuoxiu, Mr. W pointed out that the ultimate risk of nuclear power technology is its waste. Technologies of eliminating the radioactive hazards of nuclear wastes are currently unknown to us. In this respect, Mr. W is opposing He Zuoxiu. As Mr. W said to me that as a prestigious nuclear physicist He Zuoxiu should not oppose nuclear power technology, rather He Zuoxiu should use his expertise to find out new ways of treating nuclear fission wastes or to invent nuclear reactors which will make nuclear fusion reaction feasible, because either of those would ultimately solve the problem. It may be appropriate to characterize Mr. W as a typical engineer who believes in the unlimited growth of science and technology. On one hand, he believes that scientific advancements on nuclear fission and fusion reactions would finally lead to a waste free technology of energy production, but on the other hand, he also admits that such technology does not exist at the current stage. Consequently, we have to be realistic at least for now. He indicates that we need to accept the environmental prices for using this source of energy. Since engineers are not like scientists, and R&D is not a necessary task that engineers have to devote to, the only strategy left for engineers is to wait for a scientific breakthrough before taking actions to abandon the know-hows that we have. For Mr. W nuclear power is still an effective way of meeting our increasing demand of energy. Therefore, engineers need to master it and we still have a long way to go to make the system more reliable. Practically, there are a lot of things that can be done to make our system of design more predictable which represents the mastering of this technology.

Provided that Mr. W's criticism on Professor He Zuoxiu derives from a realistic value nurtured by his engineering educations, Mr. F's support of this technology is based on a firm trust of its intrinsic safety merged with his business acumen. It is also evident that in Mr. F's mind environmental activism is closely related to some small everyday life affairs. Here in CGN we are doing business. Therefore it has nothing to do with this type of problem-solving.

> Mr. F said: "I understand that the essence of nuclear power engineering is its safety culture. I also know that perhaps the general public's image of nuclear power is influenced by its negative consequences of the reported accidents. As far as I know the risk of nuclear power to impair the natural environment is the radioactive release. But using uranium to produce electricity can also be regarded as an environmental friendly technology. Compared to coal and petroleum power, nuclear power uses very small amount of fuel. The major concern is whether we can control the risk. This kind of control is achieved by our scientific design, and regulated operation. If we can make sure that no accident is going to happen, then nuclear power is a very good sauce of power. Compared to the conventional ways of electricity production, nuclear power does not require a massive scale of mining." (Appendix, G)

> "I think the most severe environmental impact of a nuclear power plant is not reflected by its commercial operation but by its decommissioning. The land used to construct the plant cannot be used for other purposes. It becomes a dead concrete dome. And this status will last for a very long time, 100 years maybe. The land will be a waste land. This is the only bad thing I can point out on nuclear power technology. For other matters, I think that, as long as we can control radioactive releases, nuclear power technology in general will benefit our society." (Appendix, G)

Inadvertently, Mr. F depicts the great divide of personal participation in environmental protection activities and the involvement of environmental activism:

> "From my personal perspective, I print on both sides of the paper. I use the printed paper as my draft paper. I seldom waste paper. I buy a fuel saving car and I care a lot about the disposal of my wastes. I think these are common environmental habits. But if you ask me about some advanced activities of environmental protection, I would say that I do not pay a greater concern on this matter. I merge environmental activities into my life. I do things that I can do. I go as far as I can to protect the environment." (Appendix, G)

> "From the company perspective, I think our company emphasizes environmental protection. It is a clean energy supplier. When you think about clean energy, that is environmental protection. As you know, we are not only developing nuclear power but also wind power, hydro power, solar power etc. But please be minded that we never construct coal or petroleum powered plants. Coal and petroleum power is far from the notion of environmental protection. Building clean energy facilities is our company's vision. In this respect, I would rather say that our company put a great effort in environmental protection. This can be

> reflected by our products. But as a business company we are not that deep green. I think our prorogation of environmental protection is performed in a relatively unperceivable manner. We are a clean energy provider, and we change the culture by our work." (Appendix, G)

The paradox of Mr. F's expressions on environmental protection is that I cannot find enough apparent correlations between his personal life and his jobs in CGN. It looks as if working in CGN is not a part of his life, or I may be able to deduce that doing business is not like living a life.

5.4. THE READING OF A BOOK – MR. YE'S AUTOBIOGRAPHY

In the previous three sections of this chapter I have portrayed some personal stories of 5 CGN engineers. All of them are quite young in age. Therefore, their experiences can only reflect a partial image of the transitions of nuclear power engineering in China, especially taking into the consideration that nuclear technology has developed in this country ever since the Mao years. In the 1980s, this technology of military origin started to be used for civil purposes. Even though I have briefly discussed about such transitions in Chapter 3 of this thesis via the growing path that went through by CGN, personal reflections and participations in these transitions still remains blank. In order to depict the human side of nuclear power engineering in earlier periods, specifically from the 1950s to the 1990s, I need a storyteller who have actually witnessed. However, it was extremely difficult to find such a person. One reason for this difficulty is that the official retirement age in China is 60 for the majorities of Chinese people, while higher ranking governmental officials' retirement can be prolonged. That is to say in CGN, officially employed engineers are all under the age of 60 except some part-timely employed consultants. Even those engineers or administrative officers around 60 years old are unable to provide first-hand detailed stories in the long 1960s and 1970s when they were just teenagers who might not exactly know what was really happening in this country. Also they were not involved in China's development of nuclear technology in its early stage.

Certainly those people with first-hand personal experiences in this period of time may still be alive, such as Professor He Zuoxiu whose voice can still be heard from time to time, or they may be somewhere living their retirement lives far away from this industry. With the help of my senior colleagues born in the 1960s and early 1970s, and are now working in CNPEC, I finally figure out two of these people.

5.4.1. A SELF-TURNED PUBLIC INTELLECTUAL

I can only give a short introduction to one of them in this thesis, and it has to be anonymous because he rejected my request of an interview with him. In the telephone call that I asked him for an interview, I explained to him that my PhD thesis was about how to improve nuclear power engineering design and importantly this part-time PhD project was approved by CNPEC. I told him straightforwardly that my approach was a cultural approach in which the human side of nuclear power engineering served as a focus. I also told him that I read his book published in 2010. In that book he made a metaphor of nuclear science and technology to a double-edged sword, in the sense that both sides of its cultural image were portrayed. Since it was a popular science reading, in which the cultural and human sides of nuclear science and technology were told as secrete stories, I thought he might be willing to give some of his personal stories about his participation in China's nuclear power engineering which were missing in his book. But he let me down, as he told me that being a well-known retiree from the Chinese nuclear industry, he tried not to be involved in some disputing discussions about this industry because that would disturb decision making of the current leadership. His rejection was made in an excuse that I could not pose any objection. He said that he was not in a good health condition. In fact, I knew he was trying to send a message that he did not want to be disturbed from his peaceful retirement life. This engineering expert is a graduate from Tsinghua University. He was born in 1941. In this respect, he is a Chinese trained nuclear science and technology expert, and importantly he must be able to provide some cultural reflections that featured the generation of intellectuals of his age. However, I can only accept his rejection as a missed opportunity for my research.

Mr. Ye Changyuan was this anonymous expert's alumni, classmate which was also highly possible. He was also born in 1941 and went to Tsinghua University to study nuclear reactor engineering in 1958. Mr. Ye was the only person that I would put his name in this empirical chapter. I may have to apologize for this because I did not get his permission in person of treating him differently from the other interviewees in this thesis. The reason for this is that Mr. Ye passed away probably in early 2012. Before his death, I did not know this person, because compared to his prominent peers he seemed to be anonymous. Therefore, it was never possible that I met him in person and carryout an interview with him. But I would here write about him and thank him for his contributions to my research, because he left a book – an autobiography – before he passed away from us.

His book titled Those Days and Those Things of Mine – literally translated into English – was published in 2014 more than a year after his death by China Culture Publishing House. I was told, but I am not sure, that he published this book on his own cost, as his last will. This book is not a popularized book in any respect. It is not sold in bookstores. It is not enlisted in public libraries' catalogues, and it is even not approachable on the internet book stores where a lot of rare books can be brought. There are two ways that this book can be read. The first approach is to read Mr. Ye's blog which has been updated by his family members, the second approach is to get a paper copy from his trusted friends. As such the book circulates in the company. One of my colleagues was a close friend of Mr. Ye. He worked with Mr.

Ye in CGN's Ling Ao Phase 1 project, when Mr. Ye was not retired yet. In this respect, Mr. Ye devoted the last a few years of his career to CGN. I got this book from the colleague. Therefore, I can use this book to fill in the blanks that I mentioned above.

In the preface of his book Mr. Ye wrote:

> "This book portrays some real life experiences of an ordinary intellectual in Mainland China. It is a window through which the lives of intellectuals of my age can be known and interpreted."(Ye, 2014, p.1)

Unlike us – China's younger generations of engineers – he entitled himself an intellectual throughout the book instead of a straightforward more professional title an engineer which is quite common in recent years. It seemed that in his age – especially in the 1960s and 1970s – these two titles were not as clearly distinguished as they are today. Intellectuals in contemporary China represent those knowledgeable people regardless of the disciplines of his or her learnings, while engineers have now been used to identify a profession – a type of technical job.

Putting this blurry or changing definition of the title intellectual into a broader social and historical context, we may be able to further clarify the changes of the cultural perceptions of science and technology in society as I have tried to describe in Chapter 2 of this thesis.

In pre-modern China, those with knowledge about social orders were named "shi" while those with knowledge and skills on natural things and the making of instruments were called "gong". In terms of social rankings, "shi" was put in the foremost position, while "gong" was placed in the third place after "nong" – those engaged in agricultural production – but before "shang" – merchants. Therefore, there was no way that pre-modern craftsman or engineers were considered as socially equivalent to intellectuals. Starting from China's long lasting modernization process, along with a re-evaluation of the two different types of knowledge – knowledge about social orders and knowledge about nature and instruments – the traditional definition of intellectuals began to change. This change can be interpreted by the expansion of the scope of "shi". Knowledge about nature and instruments demonstrated its importance in China's initial contacts and conflicts with the West. Therefore, those with such useful knowledge – which is now largely recognized as science and technology – became to be recruited into the more traditional elite social group of "shi" – intellectuals. (Xu, 2011) As a consequence those knowledgeable people regardless of their origins and learnings are regarded as intellectuals for a certain period of time. According to my estimation, a rough partition, this period of time covers the entire history of the Republic of China and the beginning two or three decades of the new socialist China.

However, in more recent years, the differentiation of engineers from intellectuals began to take place after China's Cultural Revolution which ended in the late 1970s and China's economic reforms which started in the early 1980s.

5.4.2. THE DILEMMA OF NUCLEAR POWER ENGINEERS IN 1960S AND 1970S

As I can read from the history of China after 1949, this differentiation derived from the Cultural Revolution. Specifically the reason lies in the conflict manifested by Mao's policy of science and technology which ruled China for almost three decades (1950 to 1980). This conflict can be expressed as the following: on one hand, Mao appreciated the value of science and technology and emphasized on its roles in the control and shaping of the society, but on the other hand, Mao did not give those who mastered knowledge equivalent social status.

Mr. Ye lived under this dilemma ever since 1958 when we he registered as a Tsinghua University student which symbolized his social status. From Mr. Ye's records, Tsinghua University was established by the American government which cleverly used the Qing Dynasty's indemnity for the American's losses in the boxers' rebellions. The United States was the only country among the eight powers that reimbursed such a large amount of funding to help China to establish its modern education system instead of taking such precious resources as a form of the primitive accumulation of capital. However, in the years when Mr. Ye was educated in Tsinghua, such a story was interpreted as an American culture invasion when China was in its weakest moment. It had long been perceived that Tsinghua was a school to cultivate pro-American elites. (Ye, 2014, p.96) This unique background indicated his miserable encounters in the 1960s and 1970s when class struggles, one after another, became the major themes of Chinese people's lives, including intellectuals.

In 1958, the Great Leap Forward Movement started to take place. University students like Mr. Ye were required to participate in various forms of labor work such as tree planting and digging the basement of Tsinghua University's first experimental nuclear reactor (the 200# reactor) near a river bank. He wrote that he contributed at least 100 working days full-time to this construction project with his manual work. (Ye, 2014, p.97 and 124) It was only in the relatively standby hours, in the intervals of the labor work, he and his fellow classmates were able to have some book learning. In the studying hours he felt "free and leisured, therefore I concentrated on learning". (Ye, 2014, p.124)

Revolutionary education was a major part of his life in the first two years in the university. Such education was achieved by meetings and political debates. (Ye, 2014, p.102-103) It was in the third year Mr. Ye decided on his major – nuclear reactor engineering. This is different from today in the sense that students have to choose a major before their admittance. Mr. Ye did not write why nuclear reactor engineering became his major, therefore I can only conjecture that his choice was made upon his respond to the call of the nation. The Great Leap Forward was stopped by a nationwide famine in the years from 1961 to 1962. The nation had to launch its food rationing to cope with its shortage of food. Students like him were certainly of no exception. Ironically, this famine gave the students of Tsinghua University an opportunity to perform some technological innovations, which Mr. Ye later considered as a typical Chinese humor. (Ye, 2014, p.119)

> He wrote: "In this period of time, the university asked us to participate in a technology innovation movement, to deal with the famine. We heard that treating a normal steamed bread (a type of Chinese food made of leavened dough) with ultrasonic waves, would make it twice as big. Experiments on the making of these ultrasonic steamed breads began in every canteen. We smashed one end of a stainless steel pipe and blew it with pressurized air. Earsplitting shrieks were produced and it was believed that among these high frequency sounds, ultrasonic waves exist. In a month time, we found that we failed. Then everything returned to the past but leaving dozens of smashed pipes in the kitchen." (Ye, 2014, p.119)

In these early socialist years in China, Mr. Ye's environmental concerns started to appear. In a footnote that expressed his criticism to the Great Leap Forward Movement that took place in his home town – a small village in the mountainous areas in Fujian Province – his natural conservation and human concerns related to science and technology are reflected:

> "This primeval forest which has been nurtured by the great nature for thousands of years was completed cut down in just one month, in 1958, when the local county government gave an order to the thousands of nearby villagers in the name of pumping out steel production. As a consequence, trees were cut down and burnt into ashes in the small furnaces built in the backyards. Not a single kilo of steel was produced. Not just the forest was sacrificed but also the pans and boilers from villagers' kitchens. Since no steel boilers and pans could be used, the public canteens had to be dismissed, and cooking became a great problem. People had to return to primitive lives, using earthenware pots instead. What is more regretful is that, such kind of activities which are in fact in violation of scientific laws, catastrophic to the natural environments, and completely ignorant and utopian, are still our 'forbidden zones' with which until now we cannot directly confront." (Ye, 2014, p.12)

Mr. Ye graduated from Tsinghua University in 1964, six year after his admittance, with a bachelor's degree, not because he was not qualified but because of the disturbances to the higher education throughout the country. The good thing was that he did not have to worry or even to think about his career development, for his future had already been planned by the government. He was given a job in the 401 institute which was at that time a nuclear technology military research institute in Beijing. Now this 401 institute has been transformed into China Institute of Atomic Energy, but in the 1960s it was a secret organization in which China's military researches on the nuclear bomb and nuclear submarine were performed. (Ye, 2014)

Compared to what Mr. Ye experienced from 1964 to 1978, his university years seem like a short happy hour. Mr. Ye did not claim what advanced technical knowledge he learned from Tsinghua University. However, when I read about what he was asked to do in his first job, I think it completely doesn't matter. The first assignment he received was to learn from the peasants in the countryside. He was sent to He'nan Province to work in the rice field. Willingly or not he was treated as an activist in the "Four-Clean-ups" Movement also known as the Socialist Education Campaign which lasted for 3 years from 1963 to 1966. This campaign, from a retrospective, served as the prelude of the upcoming fiercer Cultural Revolution, in which some newly established political, economic, organizational and ideological concepts were overhauled but not to a degree as it was in the Cultural Revolution.

When this Socialist Education Campaign reached to its end, Mr. Ye thought that he could return to Bejing because he considered himself to be well-educated. But Chairman Mao did not think like that. The Cultural Revolution began in 1966. In his book, Mr. Ye gave a very detailed description of his experience in the Cultural Revolution, but I would rather give a short summary of his life in those 10 years. From my perspective, his life in those years is completely irrelevant to any concrete scientific or technical content. Therefore, one sentence is enough to conclude. He received a reform through labor work, in Chinese terms. Even though he belonged to an organization – the 401 institute – his work was not done for that organization. It made me curious on how he kept his technical knowledge during the Cultural Revolution. In fact, in my perception, he did not participate in any form of scientific or engineering work for about more than a decade since his graduation from Tsinghua University till 1977.

> As he wrote: "(In 1964) When we left Beijing to He'nan Province, we were ordered not to bring any books with us, except the Selected Works of Mao Tse-tung." (Ye, 2014, p. 131)

5.4.3. A NEW ROUND OF LEARNING FROM THE WEST

In 1977, when the Cultural Revolution finally reached to its ending Mr. Ye got a chance to return back to the 401 institute, but due to political concerns his militarily secret organization was moved to the inland Sichuan Province. He had to move to Sichuan where he reunited with his family. He was saved by Deng Xiaoping's policy in the sense that Deng corrected Mao's mistakes of treating intellectuals by placing them in a correct social status. In 1978, he was "redressed". But that was ironic because he had never committed any criminal offenses expect that being a knowledgeable person could be seen as a crime. In this round of reform, Mr. Ye's identity as a Tsinghua University graduate gave him some priority. Due to his good academic records, he was appointed a visiting scholar to an Italian energy research institution called CASACCIA. (Ye, 2014)

In 1983 when Mr. Ye was 42 years old his first trip abroad started. His own experience of learning from the West started from this trip. "CASACCIA is an integrated energy research center, where solar power, wind power, nuclear power and even agriculture researches are carried out." (Ye, 2014, p. 205) It was from the learnings of the Western experience in the years of the energy crisis that triggered China's effort to transfer this military technology to civil use. (Ye, 2014) Therefore, Mr. Ye was sent to the West to learn how this transformation can be realized.

He did not write in detail about his work in Italy. What I can read from his book is that more or less he has found his idealized life – intellectual's idealized life – in that industrialized Western country.

> "The center (CASACCIA) has a powerful man-machine interactive IBM computer. Each lab has a terminal which connects to the server. It is very convenient to use. When necessary complicated calculations can be sent to the BOLOGNA /FRASCATI computer center situated in France where solutions will be generated. In fact, the European Communities has been closely connected. Information exchange is quite convenient." (Ye 2014, p. 207)

> "The center (CASACCIA) has a good library, which only needs 5 employees. It has advanced equipment. You can search through its collections of books and articles on a computer. Importantly, when you find one, you can copy or borrow the book or the article as you like, and take it out with you." (Ye, 2014, p. 207)

It was in Italy he could be away from the disturbances of the unnecessary human affairs and concentrated on his pursuit of knowledge. Mr. Ye's study in Italy was not only in CASACCIA, he also visited other nuclear power research centers such as the ISPRA. In his descriptions about his visit to ISPRA, his perceptions on nuclear power technology and his interpretations about its relationship to environmental protection can be read:

> "The host (ISPRA) introduced us in detail about their areas of research. Regarding to the composition of the staff and the distribution of funding, 50.3% percent of their research funding is used on nuclear fission reactor research, in which 54.5% is used on reactor safety studies. From this figure, I feel that they emphasizes on nuclear power technology's safety. In spite of this, 14% of the overall research funding is used on environmental science researches. Among their research staff, 54% (416/769) is dedicated to nuclear fission reactor research, and 24.5% (189/769) is employed for environmental science research. From all these figures, I come up with a conclusion that due to the severe lack of energy resources throughout the world, nuclear fission technology – this matured technology – is given a strong emphasis. In this area, a majority of financial resources and human power is spent on safety related and nuclear waste treatment researches. Secondly, environmental science is a relatively younger scientific discipline with just about 20 to 30 years of history, but considering that industrial pollution has become increasingly severe, and it gradually becomes one of the three major problems of our world. Their human resource and financial inputs into these research areas are quite visionary."(Ye, 2014, p. 211-212)

I would perceive Mr. Ye as a pro-nuclear power scientist or engineer. Not just because his comments on this technology which indicate that it is a solution to both the problem of energy shortage and the problem of industrial pollution, but because of the fact that throughout his book I cannot even find a single piece of sentence on his reflections on the Chernobyl and the Three Mile Island nuclear accidents, which he should have been aware of. The pro-science and technology culture is so dominant in his thinking that gives me an impression that for Mr. Ye, science and technology is the only solution to the problems he has mentioned. He never thought that the knowledge he admired might also be the cause of these complicated problems. In this respect, his anonymous alumnus seems to be more open-minded.

This kind of pro-science and technology tendency permeated in the later chapters of his book which described his participation in a nuclear fission reactor project in Iran, also in China's first nuclear power plant export project in Pakistan, and in his last full-timely participated project in Daya Bay – the Ling Ao Phase 1 project. In all these projects he was treated like an engineering expert. In all these projects, his situation was quite different from his experiences in the 1960s and 1970s. His voice as professional advices can be heard and accepted by others. This recovered his impaired confidence, and strengthened his self-esteem as a useful Chinese intellectual. However, it seemed to me that Mr. Ye was still not satisfied with his status in the 401 institute when he returned from Pakistan to Beijing in the 1990s when this secret military research institute was transformed into a civil organization. As I can interpret his uneasy relationship with his organization, two cultural reasons are worth studying.

5.4.4. THE PROFESSIONALIZATION OF INTELLECTUALS

In Deng's science and technology policy, knowledge development has been more closely related to economic development which indicates that scientists and engineers' contributions to economic development can be valued in financial terms. That is to say, scientists and engineers will be differentiated by their economic value which can be translated into the different levels of incomes. At the practical level, in order to differentiate salaries, a ranking system of engineers and scientists is needed. That leads to the emergence of a series of professional titles in the engineering profession, such as assistant engineer, engineer and chief engineer. Along with the rise in the ranking, the rise of power and the increase of income are accompanied. Therefore, competitions are inevitable. However, Mr. Ye was not successful in this competition to promote himself to the title of a chief engineer.

> As he wrote: "This event tells me two things: first, it tells me that I am in a bad relationship with those people who has the power to determine my fate. At any time, as long as they keep this power, they will bring the worst result to me. They have corrupted souls. In front of them, there is no fair. It also makes me determined to leave this abyss of suffering, otherwise I will not have any progress in the rest of my life. Second, in an old organization with a long history, in the past, job-hopping was not allowed. People has stayed and worked together for too long. People's perceptions on me have been fixed and cannot be changed. No matter how good I performed and how many papers I published, I am still ignored by them. At this moment, I need to move to another place." (Ye, 2014, p. 254)

In this respect, Deng's science and technology policy can be interpreted as the trigger of the professionalization of Chinese intellectuals. Since science and technology has established its market value, which was unthinkable in the Mao years, intellectuals have to be adaptive to this change. They are pushed into the market, and they have to face another mechanism of evaluation which seems to be unfair to their previous ideals. In this transition process, intellectuals, like Mr. Ye, with high self-esteems felt uneasy.

Another cultural reason for his constant disappointments with his intellectual status can be found in China's cultural heritage. Being an intellectual with an analogy to "shi" is supposed to enjoy certain privileges in society, which Mr. Ye once enjoyed when he left his high school to Tsinghua University.

> "On the day I left my high school, the county people beat gongs and sounded drums, as a farewell ceremony to celebrate my success. The county newspaper put my admission to the Tsinghua University a top headline in the front page. I was the first Tsinghua University student in this history of our county. I was treated like the number one scholar in the imperial examination as if I were a historical figure in imperial China. My admission made our principal and my father extremely excited." (Ye, 2014, p. 84)

But one of his returns back home in 1978 was not that excited:

> "In February 1978, after a 5 day and 4 night's tiring travel, I finally arrived at the nearest train station to my home town. Retrieving this journey, it was unspeakably miserable. At that time, a prominent university graduate like me, my money was just enough for making a living. In such a long distant travel, I could not afford a berth ticket. (In fact it was not for sale.) In the waiting for a transit train, I had to crouch on the floor to spend the long night with the vagrants in rags. We were driven like a herd of ducks back and forth in the station." (Ye, 2014, p. 2)

What I can read from these sentences is that Mr. Ye takes intellectuals' reception of privileges for granted. It may have no wrongs of holding such a perception, because it is a part of the Chinese culture. But from a more liberal point of view, eradicating such habits is also an idea that deserves encouragement. In this respect, Chairman Mao was not completely wrong. Compared to Mao's, Deng's science and technology policy can be interpreted as in conformance with the human nature of making a better living. They all make sense. Perhaps a hybridization of all these perceptions consists of the cultural image to intellectuals in China today.

In fact, Mr. Ye made a critical mistake throughout his life. He spent all his life knowing a lot but did not figure out the most important solution to answer to all his mishaps as he perceived in his book. This important know-how for intellectuals to live in China over its history is to work with power instead of against it. Ironically, this has been a part of our culture for thousands of years ever since the Confucius time.

5.4.5. MR. YE'S ATTEMPTS OF IMPROVING ENGINEERING DESIGN

In general, the last a few years – perhaps since 1996 – of his career in CGN were quite satisfactory to Mr. Ye. On one hand, his was respect by his younger colleagues as a tough old guy (Ye, 2014, p.257), and on the other hand, his salary was dramatically raised due to the leadership's appreciation of his work. (Ye, 2014, p.265) He served as a construction quality assurance specialist on site for the Ling Ao Phase 1 project (1996-2003). After his official retirement in 2001 he was still hired on a part-time basis until his death. Being critical served as a motif of his work in CGN. During his stay in CGN, he wrote 57 letters to express his opinions about the problems that he found in the construction of that nuclear power plant to CGN's leaders. (Ye, 2014, p.265)

In one of his letters he wrote something about the problems of engineering design appeared in the Ling Ao Phase 1 project.

> "Foreign designers made some mistakes in their interface management. This led to a series of non-conformance construction and installation activities with the design… … for example, 64 holes each with a diameter of 500mm needs to be penetrated in the UJE building for the installation of brackets to support the main steam transmission pipes and the main water circulation pipes. This was a huge design mistake, which endangered the stability of the concrete structure of the nuclear island. According to NNSA's (HAD003/06) nuclear safety regulation, designers must issue a NCR, and report the handling of this incident to NNSA. Additional costs caused by these mitigations shall be borne by the designer. As far as I know, in the nuclear island design, up till now, more than 2000 items of design variations have been issued. It is said that we agree to treat these variations as design modifications. That is to say the accompanied additional cost will be borne by us. In fact, we need to distinguish the different natures of these design variations. It is evident that those variations in terms of correcting design mistakes cannot be treated as normal modifications. All the additional costs caused by these mistakes should be borne by the designer." (Ye, 2014, p.264)

> "The fuel transportation vehicle was missed in the design… … it means to me that the designer's sense of responsibility needs to be questioned! The validity and effectiveness of the designer's quality assurance system remain to be doubted and challenged." (Ye, 2014, p.264)

Mr. Ye was an honest and responsible man, but he did not give a feedback on how these problems were finally solved. According to the classification of CGN engineers, Mr. Ye's position in CGN can be regarded as a project management engineer. Perhaps due to confidentiality reasons, throughout his book nothing technically detailed was given about his engineering activities in the 401 institute. But Mr. Ye did witness CGN's transition of engineering design from an owner typed to a contractor typed design. Even though, frankly speaking, his book is not helpful to trace the evolution of China's nuclear power engineering designs since the 1960s, it reflects the transitions of our past nuclear science and technology intellectuals to the contemporary scientists and engineers.

CHAPTER 6. CONCLUSIONS AND IMPLICATIONS

6.1. CONFLICTS BETWEEN ENGINEERS AND THE ORGANIZATION

In the previous chapters, I have argued that in China nuclear power development is surrounded by a mind-set that relates science and technology to economic growth or more directly to the accumulation of power and wealth. Science and technology is utilized as an instrument to achieve that end, which also indicate an appropriation of the scientific methods to solve nuclear power development related social problems. In this thesis it is implied that such a dominant commercial culture has its influences on CGN's engineering design practices. Such influences are reflected by CGN's design organizations and engineers' understandings of engineering design.

Chinese nuclear power development plans emphasized the "technology-push" (Dosi, 1982) effects of this technology, and consequently in order to bring it into the society, a "market" has to be created as it appeared in the 1980s. With this market, nuclear power technology can be advertised as a realistic solution to the energy and environmental problems and the notion of nuclear safety can be further interpreted into national nuclear industrial safety regulations and standards which are, from an economic perspective, a set of rules that legal persons must subject to in order to survive in the market. From a more practical perspective, these rules are translated into a systematic contractual language. As a consequence a chain of commercial responsibilities becomes consummate.

In this chain, companies like CNPEC and CNPDC are responsible for providing an intrinsic safety of the nuclear power plant through their designs and construction activities. The manufacturers offered a solid material foundation of achieving this safety claim, by means of meeting the high demanding quality standards. Externally, from a CGN perspective, the interactions among the market players are restricted inside this specific market, and internally inside the organization, such contractual responsibilities are broken down into achievable technical goals which the established scientific and technological paradigms are able to solve. It seems to me that such divisions and connections of contractual responsibilities serve as the ground principle that shapes the division of labor, the structure of the organizations, and the definition of interfaces in the entire nuclear power industrial sector.

Negative implications related to this ground principle are quite evident. On one hand, it restricts companies' communications with the broader society. It seems that the border of such kind of external communications can only encircle the nuclear power market players. The civil society is excluded because it is considered as troublesome and needs to be educated. It may also be reasonable to perceive nuclear power developers' public opinion surveys as a form of commercial advertisement which intends to promote public acceptance of their products by persuasion. On the other hand, such kind of interactions of nuclear power market players with the society make them numb to the public opinions because under the protection of science and technology as a form of privileged knowledge, cultural or social criticisms to this technology are treated as less proved ideas compared to the scientific evidences and technological guarantees. Even the prestigious "public intellectuals" found themselves feeble in changing the directions of nuclear power development initiatives both at the local level and at the national level.

Design engineers are situated at the far end of this contractual responsibility chain. Nuclear safety regulations, technical standards together with company norms are turned into criterions that are used to evaluate their performances. Terms and conditions in the contracts are further translated into their tasks and every day routines. Rather it is to say that the definition of CGN design engineers' scope of work emerged scientifically or technologically from the demarcations of disciplines or area of expertise, than to say that the overly specialized division of labor in CGN's engineering design is generated from a clear cut of bordering responsibilities. This leads to the two major problems of engineering design practices identified in Chapter 5: first, the difficulty of cross disciplinary internal communications – excessive meetings and multiple reporting; second, a lack of experience and sensitivity of technical changes and site variations among CGN designers – unfamiliar with technical standards, no sufficient experience in handling site variances, and a habit of relying on duplications of verified results.

These problems of engineering design in CGN can be perceived as the problems of the system rather than individual designers' problems. In addition, these problems generate a cognitive differentiation between the perceptions of good nuclear power plant's engineering designs from a company perspective and designers' own recognitions of what a good designer can do. The company has launched various schemes of improving engineering design systematically, but the designers still find too much of their time is wasted on non-technical related affairs. In this respect, would it be proper to say that these company schemes are all failed attempts?

From a commercial perspective, the answer is not definite. In spite of the knowledge management system which is designed and implemented to make the searching and utilization of knowledge more convenient, a technical configuration management system is transplanted from AREVA to CGN for the purpose of tracing of technical modifications and changes among CGN's on-going projects. (Wan et al., 2013) CGN's approaches of improving engineering design are immersed into its established quality assurance, quality control, and project management systems. However, the evaluation of the effectiveness of these management systems is largely unaccomplished partly due to the difficulty of establishing a mathematical model to quantify real life engineering design practices and partly due to the fact that in order to obtain sufficient statistical confidences such an evaluation has to be performed after the projects' final accounting. Although an online evaluation of such systems is possible, its interim conclusion can never be definitive enough from a statistical point of view. Therefore, CGN is running these systems on a hypothetical forecast of their cost saving or revenue increasing potentials.

In general, the company idealized engineering design as a production process, with an ultimate goal of increasing profits. Its approaches of improving engineering design are based on reducing uncertainties and eliminating unpredictable results. On top of this, in fact, social or human factors in engineering design are treated as uncertainties and interferences. As long as procedures, flows, and organizational structures can regulate human activities, they should be favored approaches of ensuring good results. Perhaps, such a de-humanized engineering design is what the company considers as a good design.

From the outset, CGN engineers' wants of becoming more technically competent engineers with less non-technical disturbance in their everyday lives can be considered as in line with the company's intention. This impression can be interpreted as the consequence of the dominant commercial culture that is inculcated into the engineers' individual habits. This can be reflected by the positive perceptions to technical innovations both at the company level and the personal level.

However, innovation, in terms of the development of new types of nuclear power plants, such as the HL1000 plants, is also a production process. Compared to the engineering designs in the CPR1000 projects, the procedures, tools, and management systems used in the HL1000 designs are no different. The only difference between the CPR1000 and HL1000 designs is the organization. In the HL1000 design, a specific permanent design team is formed rather than the matrix style of design organizations used in the CPR1000 designs. That is to say that the designer is solely employed by the HL1000 project instead of the previous simultaneous involvements in multiple projects. Admittedly, this slight difference cannot indicate a fundamental change of CGN's engineering design in its R&D project. It is exactly the same that in the HL1000 project designers are required to be precise, time bonded and economically realistic.

From my point of view, the differentiation between the company's ideal type of a good design and the engineers' perceptions of good practices cannot be resolved by this impressionistic similarity because the fundamental differences between the two can be found in the different perceptions on engineers' identity. For the company engineers are modeled to be instruments, which produce outputs from inputs. The aim of the company is to make the production efficient. In contrast, engineers try to be more useful not just in the sense of being more efficient but also becoming more knowledgeable that indicates producing more useful knowledge. The definition of identity appears to be more social in the minds of engineers than in the models of the company. This leads to the tendency that engineers agrees more on the perception that engineering design is a social process rather than a program of producing documents.

6.2. COMPROMISES TO THE ORGANIZATION

In CGN, a seemingly trade-off of such conflicts is achieved by two ways. On one hand the company uses its financial power to channel engineers' pursuit of becoming technically more competent people. On the other hand, in order to cater that strong power engineers choose to adopt a compromise.

The company's approach can be reflected by its human resource policy. In April 2013 I was mandated to take an internal training course named "Achieving Best Performance". This course was among a series of courses under a self-development scheme which covered the entire CGN Group. This scheme started in 2009, not long after I joined the Taishan Project Management Office in CNPEC. The scheme was generated from the consultancy advices of a human resource consultancy firm named Development Dimensions International (DDI) to CGN. My personal understanding of this scheme is that it serves as a managerial tool to channel employees' self-development by indicating what kinds of skills and personal characteristics are considered as important by the company. A series of internal publications and tutorial courses have been developed to facilitate its implementation, and the scheme has been turned into a management system. Every employee, engineers and managers, is required to take part in some courses to help the person to develop those enlisted abilities and skills. A quarterly report to the supervisor of engineers' progresses is mandatory.

It is a typical performance assessment system, and at the end of each year everybody in CGN will get a grade A, B, C or D. These grades will be used to decide engineers' promotions in the following year. But it seems to me paradoxical that this evaluation of engineers' performances is based on the supervisor's impressionistic measurements of how the abilities are manifested instead of a more direct accounting of how much work is done. This paradox can be explained by the intention of adopting this scheme in the sense that the aim is to strengthen engineers' attachment to the company and its culture. In a negative tone, this approach limits individual pursuits of becoming good engineers because it filters those characteristics that the company considers as unnecessary.

Chapter 4 is an example of how CGN engineers compromise to the company. This kind of compromises can also be reflected by the proposals of improving engineering design provided by the interviewees.

Table 6-1 Proposals of Improving Engineering Design

Name	Problems of Designs	Proposals to Improve	Background
Mr. G	• Overly Specialized Division of Labor; • Too Many Non-technical Tasks.	• Job Rotations; • Mapping Unknown Knowledge; • Learning plus Doing.	• Learning from the West in a Technology Transfer Project.
Mr. L	• Lack of Standardized Format of Engineering Design (Appendix, D) • Lack of Trans-disciplinary Mobility.	• Learning by Comparing and Evaluation; • Being More Specialized.	• Studying Verified Designs.
Mrs.'s	• Experience Comes from Details; • Civil Engineering Design should be Site Oriented.	• Learning by Doing; • Working on Site.	• More than 20 years involvement in Different Civil Engineering Projects.
Mr. W	• Less Knowledge and Sensitivity to the State of the Art of the Industry.	• Gaining Shop floor Experience or Employing Manufacturer turned Designer.	• Communicating with Industrial Manufacturers.
Mr. F	• Less Competent of Generating Technical Innovations.	• Company Supported Research and Developments.	• Practices in Intellectual Property Trades.

Table 6-1 is highly identical to the list of the existed actions of design capacity building attached in Appendix A. The similarity can be expressed in the following three aspects:

First, proposals that require less external resources can be included in the company scheme. Such as the knowledge mapping activities which are achieved by voluntary participation at no cost at all.

Second, immediate results instead of long term efforts without apparent outcomes are more appreciated. Mr. G and Mr. L utilized their learnings directly to engineering modifications. As a result they enjoyed a chance of getting more training in the technology transfer project, and gained some advantage in their promotions. Due to the fact that Mr. W and Mrs. S's proposals are in fact long term investment, they can be replaced by market alternatives, in terms of recruiting ready expertise directly from the market.

Third, CGN favors outcomes that have potential market values instead of just technologically novel. This indicates that Mr. L's participation in the 3D-printing study group can only be a kind of hobby at this moment. As long as this technology is not readily to be used to the manufacturing of nuclear power plants' equipment it will be extremely difficult for him to attract company funding to support his personal research interests. It also explains why Mr. F's proposal of emphasizing on technology innovations can only be realized when it is almost certain that certain innovations can be implemented in the foreseeable future such as the HL1000 project. The company's opinions toward technology innovations during its normal operation periods are quite reluctant.

The effects of a culture filter seem to be evident in the company. Conceptually this filter represents a selective function similar to Grimson's (2009) findings about the social sections of technology. In CGN the mechanism of selection is reduced to market variability. This means the filter of the commercial culture would phase out those economically irrelevant signals to a main discourse so that these signals can never be influential to the established culture.

Regarding to the three meanings of engineering, in CGN; the economic meaning overwhelms the scientific and human meanings. However its filtering effects on the human meaning seem to be stronger than the scientific meaning. The scientific meaning can find its places in organizational culture by making a compromise. In fact it is a kick back strategy also used by the company in the issue of the popularization of nuclear power related scientific knowledge. Engineers use this strategy to ask for more company investment in their pursuits of more scientific knowledge. However, the human meaning is completely screened out. Not only that the company misuse this meaning to advertise its products, but also the engineers think that it is irrelevant to their pursuits. Work and life are clearly divided. Becoming good engineers becomes a pursuit that can only be discussed in the working context.

Even though engineers want to be treated more human by the company, they are not expressing it in their proposals to the company. Some complains about the burdens of multiple reporting and lack of cross-disciplinary corporation are expressed in economic terms – in the name of wasting time which indicates a higher cost of production – needless to say, to raise critiques from an environmental perspective or a social justice perspective on nuclear power technology. In this regard, to change this “clean” company to a green company never appears to be even a topic of the company’s reform policies. Therefore, becoming green engineers cannot rely on the company.

6.3. TO THINK OUTSIDE THE BLACK-BOX

In this thesis, it is indicated that turning green is a path to become a good engineer. Now, I want to make this argument more clear because I think it is an urgent problem that Chinese engineers need to solve even from an economic perspective.

In May 2015 I visited the AREVA Tower in Paris for perhaps the last project meeting between AREVA NP and CGN on the transfer of EPR technology. The estimation of the closure of this contract which is stipulated to be effective for 20 years is that AREVA is going to be dismantled. This is completely out of the expectation of CGN that its mentor in nuclear power industry is going to disappear in the market from a legal point of view.

In recent years, AREVA has suffered from huge cost overruns in its two projects in Finland and in France, bad investments in uranium mines and a general slump in demands for new nuclear reactors after the Fukushima disaster in Japan four years ago. After years of losses, AREVA is currently in the midst of a major cost-cutting effort and planning to reduce its global payroll by cutting 5,000 or 6,000 jobs. As a result EDF is possibly taking over some of AREVA’s assets to maintain the livelihood of nuclear power technology in France. (New York Times, Accessed, June 4, 2015) I witnessed some vivid counteractions responding to EDF’s taking over of AREVA. I saw union leaders giving out booklets and papers at the entrance of the canteen to express their disagreements of such a deal. I was told by my counterpart in AREVA that in a few days a strike was going to happen.

All these lead me to think: Is AREVA a victim of his own hubris? Will CGN be one day like AREVA? Is this the last lesson that AREVA teaches CGN? Will CGN engineers be turned into anti-nuclear power activists when they are in danger of losing their jobs?

The AREVA case means to me that willing or not sustainable development has become a theme of the future of engineering. This theme reflects a balanced development of the scientific, economic and human meanings of engineering. Perhaps we have learned enough from AREVA on how to combine the first two meanings. But the development of the third meaning is something we cannot learn from AREVA. Precisely, it is not something that can be learned in the organization. It is something that we need to learn outside the black-box.

Being green means the engineers take their social responsibility. In a company like CGN keeping the business as usual has been interpreted as a fulfillment of that responsibility. But the AREVA case tells us that this interpretation is wrong. The real opportunities of a “sustainable development” of a business is perhaps a balanced development in the sense that making the advancement of engineering responsible. (Jamison, 2013) In respect to individual engineers, it requires engineers to take their social responsibilities as social men rather than organizational men. This change means that engineers shall combine their lives with their work, in the sense that to think more about other social members rather than themselves. In this change we may need to reshape our perceptions of science and technology in order to understand the authentic meaning of our social responsibilities.

For contemporary Chinese engineers, I think, we are now in a better situation than our modernist predecessors because our cultural heritage to assist us to reshape our visions is not completely barren. Mr. Ye’s book inspires me that we may reshape our social identity as intellectuals. In fact, we can be better than him, if we fill this old identity with both some old and new meanings. To do this, a new reading of our cultural heritage is required.

In a book named zhi shi fen zi de li shi yu wei lai (Xu, 2011) literally translated into English as The History and Future of Chinese Intellectuals, Professor Xu Zhuoyun[23] portrayed the historical changes of Chinese intellectuals especially in its modernization process. As he briefed that in pre-modern China, Chinese intellectuals were nurtured to serve as government officials – the title can also be interpreted as public servants. When Western science and technology has taken the place of Chinese learning as privileged knowledge, it seems that the notion of intellectuals has also changed. As he put it “specialists take the place of intellectuals”. (Xu 2011, p. 12) According to Xu, this transformation is a fundamental redefinition of knowledgeable persons in China. This tremendous change explained why Chinese intellectuals become bewildered about their roles in society. But as it is to Xu, in fact, Chinese contemporary intellectuals shall go back into their historical heritages to find their responses to these changes.

Over the years, Chinese intellectuals established four ideal types of their social roles. The first type can be seen as philosophy oriented, in the sense that intellectuals shall try to provide to the members of the society with rationality. The

[23] Xu Zhuoyun, Professor Emeritus University of Pittsburgh, Hu Shi’ student in National Taiwan University.

second type is service oriented. With the power of knowledge, Chinese intellectuals shall serve the people, and establish, to a certain extent, a leadership. The third type of intellectuals devotes their lives on the impartment of knowledge as such knowledge can be passed down through generations. The fourth type, compared to the above categories, seems more ideal. This type of intellectuals devotes their lives to change the society. Sometimes they point out a direction of progression that people has never imagined. While mostly, they criticize actions and behaviors which are wrong. (Xu, 2011)

Certainly, Chinese intellectuals can choose to be one of a kind, and in any case being one kind of these ideal intellectuals is not easy. But, Confucius, perhaps the most significant figure in the shaping of Chinese culture thought that a perfect intellectual shall be a hybrid of all these types[24]. In this respect, it is quite obvious for me, that the traditional culture supports a combination of knowledge mastering and making. This corresponds to a balanced self-development in this thesis.

In addition to these contemporary readings of the Chinese canons, some late interpretations of the Confucian works are highly relevant to replace our utilitarian perceptions of science and technology. A famous neo-Confucian scholar in the Ming Dynasty (1368-1644), Wang Yangming[25], in his writings, expressed his distinction of good and evil. "Those who and which thrive lives are good, while those bring about death are evil." (Qian, 2010) In my opinion, this is the criterion that every Chinese engineer should keep in mind above any type of engineering codes, and regulations because with this distinction in mind, engineers may know what should be learned from the society and what should be made for the society.

6.4. THEORETICAL IMPLICATIONS

I would like to draw my conclusion of this thesis in a deductive and concise manner which may be more convincing to my engineering colleagues in China.

How to be a good engineer?

My answer is: First you have to be a social man.

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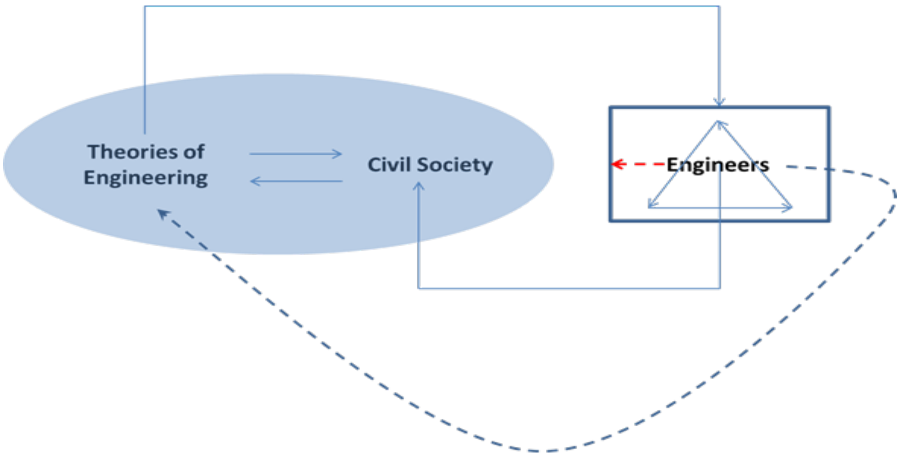
[24] The Great Learning, The Four Books: The Basic Teachings of the Later Confucian Tradition, Daniel K. Gardner, Hackett Publishing Company, Inc. (2007)

[25] Wang Yangming (1472 – 1529) was a Chinese idealist Neo-Confucian philosopher during the Ming dynasty. After Zhu Xi, he is commonly regarded as the most important Neo-Confucian thinker, with interpretations of Confucianism that denied the rationalist dualism of the orthodox philosophy of Zhu Xi. https://en.wikipedia.org/wiki/Wang_Yangming, (Accessed, December 15, 2015)

This answer comes from my observations of what's wrong in reality in contrast to the theoretical framework of this thesis.

Figure 6-1 what's wrong in reality?



The solid lines in this diagram represent the theoretical depictions of the interactions between engineers and the culture. It has been argued or proved in this thesis that in order to make the evolution of engineering in a responsible way such interactions shall shape a circulation. The critical relationship is the line that connects engineers with the civil society.

The reality that I have observed is that this line doesn't exist. Either it stops at the border of the black-box representing the company as it can be expressed by the dotted line in red, or it curves and points to the theories of engineering as it is expressed by the curved dotted line in blue. The red dotted line corresponds to the phenomenon of changing the organizational culture inside the system. It failed to penetrate the black-box due to the strong power of the culture filtering. The blue dotted line corresponds to those renegades such as Professor He Zuoxiu, who adopts an escape strategy to change the culture. Normally they choose to influence the culture by contributing to the theory of science and technology, and in that sense they are not engineers anymore. That is why this path is tortuous.

The problem here dotted lines cannot manifest engineers' direct contributions to the society and to the culture because their work is simply done for the company and in the case that I have observed is that such contributions to the society is highly controversial. The circulation is impaired by such a failure of penetration. The escape from the organization is considered as less useful to promote the circulation of interactions because when the renegades escape, they belong to another cultural domain while the circulation cannot be maintained with an empty element.

So the solution is that the red line has to penetrate through the black-box as it is predicted by the theory.

How?

The answer is: It needs a hybrid imagination which starts from reflections of experiences.

At the end of this thesis, I want to express some of my hopes. Once I was a student of engineering in a Chinese engineering university, just like most of my colleagues in this company. From a retrospective, we have been trained to be qualified organizational men. As I can remember, we were imparted with the progressive image of science and technology by the Chinese version of the theory of science. After our graduation we consider ourselves as social elites, because we know how to make things that will enrich our country, our people, and ourselves. We may have the wit to work with others, but we may not know enough to live with others. To some extent, I am taught by Aalborg University, and spent many years to get a sense of feeling that a character of hubris exist in me. In reality, I find that Chinese engineering schools have not changed in their ways of educating engineering students on the relationship of science technology and the society. In this respect, I feel it a great pity because if engineers do not know the meaning of a better life rather than a richer life, how can they help to build a better life for others? I hope this can be learned in the universities in the future. If that is not going to be the case, I hope they can learn it from the society by themselves because that is what a good engineer can do.

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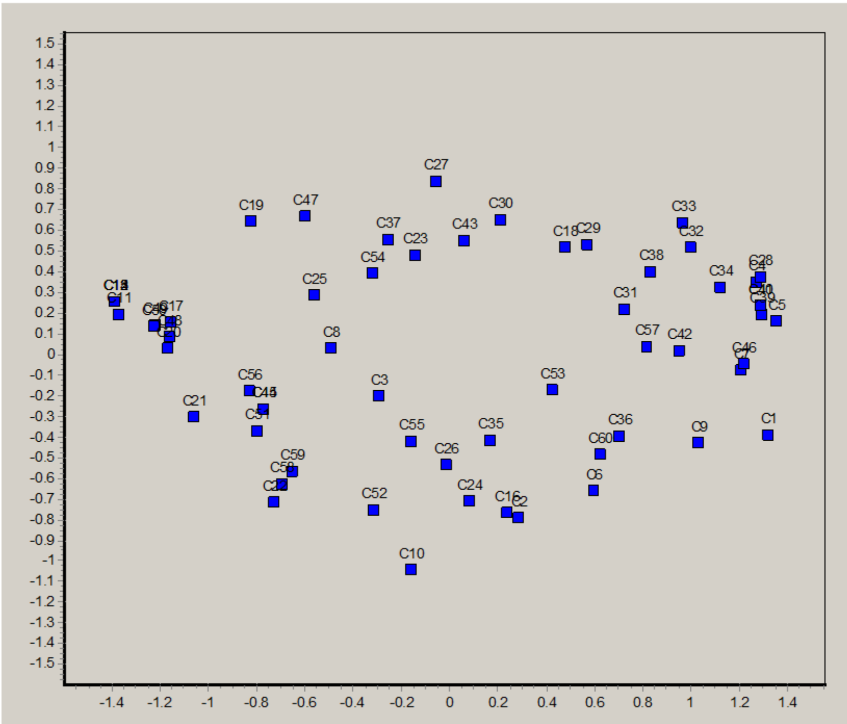
APPENDICES

Appendix A. Main Results of the Self-Motivated Research

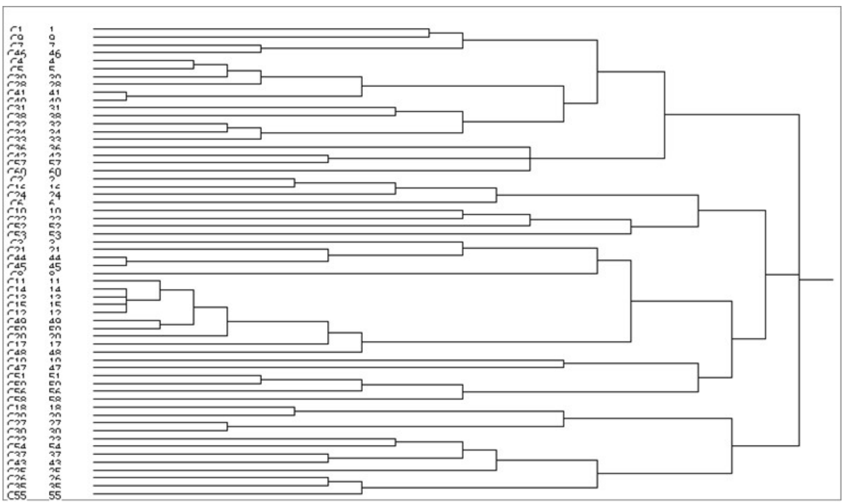
60 Engineering design capacity items

G1	C18	Compliance With Industrial Laws and Regulations	遵守工程设计法律法规
	C29	Compliance with Design Procedures	遵守设计流程与规范
	C27	Environmental Consciousness	环境保护意识
	C30	Industrial Health and Safety Consciousness	工业健康与安全意识
G2	C25	Consciousness of the Scope of Work and Responsibility	工作范围和责任意识
	C37	Marketing Consciousness	市场意识
	C43	Quality Control and Assurance Consciousness	质量控制与质保意识
	C23	Cost Control Consciousness	成本控制意识
	C54	Risk Control Consciousness	风险控制意识
	C26	Planning (Time-scheduling and Elements of Production)	计划能力（进度、生产要素）
	C35	Understanding of Goals to be Achieved by the Project	理解把握项目目标
	C55	Ability to Deal with Variations and Deviations	能够应对情况变化与处理偏差
G3	C6	Ability to Clarify Engineering Problems and Scenarios	阐述工程问题能力
	C2	Ability to Perform Deduction and Induction Reasoning	综合推理逻辑能力
	C16	General Rationality	通用常识与推理
	C24	Ability to Simplify Complicated Scenarios	问题简化能力
G4	C10	Awareness of Interfaces of Engineering Units	接口理解与协调能力
	C22	Communication Skills (Verbal)	语言沟通技巧
	C52	Ability to Balance Technical Concerns, and Concerns across Technical and Social Domains	平衡各种技术与社会关注
	C53	Reflection of Experience and Offering Options	提供经验反馈与建议
G5	C8	Objectivity Toward Engineering Matters	对工程问题保持客观
	C3	Curiosity and Sensitivity to New Knowledge	对新知识的好奇与敏感（学习能力）
	C21	Imagination and Creativity	想象力、创造力
	C44	Ability to Make Judgments	判断力
	C45	Independent Thinking	独立思考能力
	C48	Remain Skeptic	保持质疑
	C17	Ability to Absorb and Understand Diversified Views and Ideas	包容与采纳不同观点
	C20	Ability to Work in a Group, Partnership/Cooperation	合作、协作精神
	C11	Honesty	诚实
	C13	Patience	耐心
	C14	Commitment to Hard Work	敬业、吃苦
	C15	Persistence	执着与坚持
	C12	Prudence	审慎、细致
	C49	Ability to Work Under Pressure	抗压能力
	C50	Ability to hold a Self-control against Emotional Disturbance	自我情绪控制
G6	C19	Aesthetics Humanities and Arts Awareness	人文、审美、艺术修养
	C47	Phylosophical Thinking	哲学思维（认识论）
G7	C58	Skills in Technical Negotiations	谈判能力
	C56	Ability to Endure Confrontations	化解矛盾
	C51	Leadership and Organizational Skills	领导与组织能力
	C59	Self-motivated and the Ability to Motivate Others	主动性与推动工作的能力
G8	C33	Familiar with Industrial Trends and the Development of Technology	熟悉行业动态与技术发展水平
	C32	Familiar with Technical Standards	熟悉技术标准
	C34	Familiar with Equipment Manufacturing Technique	熟悉设备制造工艺
	C31	Engineering Experience	积累工程经验
	C38	Awareness on Reference Engineering Projects	了解参考项目与样板项目
	C28	Ergonomics Knowledge and Concerns	人体工程学知识
	C4	In-depth Engineering Knowledge of at Least One Discipline	某专业的深入工程专业知识
	C5	Cross Technical Discipline Understandings	跨专业工程知识
	C39	Knowledge of Related Construction and Equipment Materials	工程、机械材料知识
	C41	Knowledge about Operation and Maintenance	了解运行与维修技术与流程
	C40	Knowledge about Erection and Commissioning	了解安装与调试流程
	C1	Ability to Carry out Experiment and Test	试验与测试技能
	C9	Ability to Setup Mathematical Models and Perform Quantitative Analysis	数学建模与定量分析能力
	C7	Ability to Read/Understand and Make Engineering Drawing	工程制图、读图能力
	C46	Master Quantitative Analysis Computer Codes and Design Software	工程设计软件应用
G9	C36	Ability to Perform Technical Feasibility Studies	能开展可行性研究（技术）
	C42	Master a Foreign Language	掌握一门外语
	C57	Technical Reference Survey	技术资料搜集与检索
	C60	Data Collection and Manipulation Skills	数据收集与处理能力

A MDS map of the 60 items

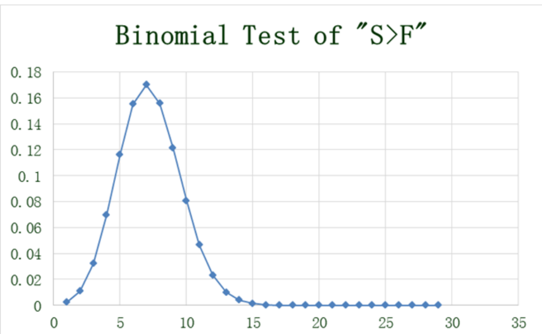


A pile sorting dendrogram of the 60 items



A binomial test of the approaches of improving engineering design

Actions	Explanation	S>F	S<F	S=F	Binomial Test
Intentional knowledge transplantation	Use nuclear power engineering knowledge in non-nuclear power engineering projects (In CNPEC the "Concentric Circle" projects refer to this kind)	10	7	12	0.080769103
Answering nuclear safety related questions raised by NNSA		16	2	11	0.000375384
Cross disciplinary appointments	For example: civil structure engineers take part in heat and ventilation system design and vice versa	16	6	7	0.000375384
Obtaining qualification certificates	For example: chartered civil engineer or chattered pressure vessel designer	17	3	9	9.56861E-05
In-depth understanding and practice regarding to the meaning of precision in engineering design	A deep understanding of construction and manufacturing techniques used on-site, with an awareness of to what level the precision requirements of design can be achieved. This understanding shall rely on a witness or participation site works.	17	3	9	9.56861E-05
Job rotation in one discipline	For example: layout designer switched to structure analysis as a form of training	17	4	8	9.56861E-05
Assessment of the result of the same type of engineering design	For example: an assessment of EPR and AP1000 design	19	5	5	4.1035E-06
Participation of testing and verification	Performing system and equipment functional test	20	2	7	6.83916E-07
Out-reach of Expertise	For example: an equipment designer was given the opportunity to participate in system design or overall design	20	1	8	6.83916E-07
Academic Pursuit	Advancement in Academic Degrees	20	1	8	6.83916E-07
Feedback of Engineering Project Experience	Knowledge sharing in the form of providing self-reflections of engineering experience	22	2	5	1.18427E-08
Mentor and Apprentice Mode of Coaching and Training	Junior engineers benefit from this type of on the job training program	24	1	4	1.00119E-10
Engineering Academic Communications	Engineering academic journal publications and attending conferences	24	1	4	1.00119E-10
Participation in R&D Projects	For example: ACPR1000+ project and engineering modification designs	25	1	3	6.67463E-12
Joint Design	Working under a joint design team consisted of engineering partners such as Areva	25	2	2	6.67463E-12
Solving Non-Conformance Problems	NCRs and DENs	26	0	3	3.42289E-13
Making Engineering Documents	Specifically design procedures and calculation notes	26	1	2	3.42289E-13
Being a team leader	To establish planning and organizational abilities	26	1	2	3.42289E-13
Participation of Technical Exchanges	Industrial investigations, polytechnic exhibitions etc.	27	0	2	1.26774E-14
Technical knowledge and skills training	For example: computer software calculation, engineering graphic drawing, and welding practice etc.	27	0	2	1.26774E-14



Approaches of improving engineering design related to the types of design

Proposals of Improving Engineering Design	Types of Engineering Design
Answering nuclear safety related questions raised by NNSA	Owner-typed engineering design capacity building
Cross disciplinary appointments	
Obtaining qualification certificates	
In-depth understanding and practice regarding to the meaning of precision in engineering design	
Job rotation in one discipline	
Assessment of the result of the same type of engineering design	
Participation of testing and verification	Contractor-typed engineering design capacity building
Out-reach of Expertise	
Academic Pursuit	
Feedback of Engineering Project Experience	
Mentor and Apprentice Mode of Coaching and Training	
Engineering Academic Communications	
Participation in R&D Projects	Innovator-typed engineering design capacity building
Joint Design	
Solving Non-Conformance Problems	
Making Engineering Documents	
Being a team leader	
Participation of Technical Exchanges	
Technical knowledge and skills training	

Appendix B. Interview with Mr. G

Mr. G is the newly appointed technical manager of our NITT project representing CGN. He is the fifth NITT technical manager. Compared to his predecessors he is the youngest. The reason that I want to interview Mr. G is that I have heard of him as a system design engineer before he is switched to a managerial position.

Mr. G started our conversation by describing his perceptions of design work and career development. He traced back to what he called “the knowledge foundations” established in his university educations.

He was educated to the master’s level majored in Nuclear Power engineering from China’s most prestigious engineering university Tsinghua University.

He entered Tsinghua in 1997, after that he spent almost 7 years in that university, the first four yeas till 2001 was a standard 4 year training leading to a Bachelor’s degree, and another almost 3 years post-graduate study leading to a Master’s degree. In 2004 he was employed by CGN.

Mr. G made a strong connection of his education to his career development. He thought that what he did in CGN and his engineering education perfectly matched. He made several examples of how his bachelor’s education was programmed to illustrate this connection. First he gave an example of his study visit to the university’s experimental nuclear reactors, and later his industrial visit to Qin Shan Nuclear Power Plant. Second, he portrayed how he accomplished his bachelor’s thesis by making a sort of visual demonstration of a nuclear power plant system.

He made the following statement to describe his postgraduate education: “The master’s study is even more specific than the bachelor’s study.”

“ In my master’s years, I participated in a joint R&D project between CGN and Tsinghua. That was the reason why in my second year as a postgraduate student, I came to Daya Bay. The topic of my master’s study was a heat exchange study on a piece of equipment in the conventional island. My task was one part of a bigger research project on the heat exchange system of the entire plant. After I have finished my task here in Daya Bay, I went back to Tsinghua to defend my thesis, and got the degree.”

“ In 2004, after I graduated from Tsinghua, I was employed by CGN in an organization named the Technology Center of CGN Group at that time.”

“CNPEC was established in the year 2003 and at that time the Technology Center was an independent entity in the CGN group for the purpose of providing technical consultancy services to new-built plants and technical upgrade of the existing units.”

“ Later when CGN decided to set up its design institute, people employed in the Technology Center were distributed to the divisions of this newly established design institute namely CNPDC. Therefore, the Technology Center became the predecessor of CNPDC’s Nuclear Island System Design Division and the Rector Engineering Design Division. The conventional island design division was at the beginning a joint group consisting of some engineers dispatched from the GEDI (Guangdong Electricity Design Institute) and some engineers majored in conventional island engineering who originally worked in CGN. Such an arrangement of the conventional island design team was in fact a consequence of CGN’s investment to GEDI. It was in 2005, when the Ling Ao Phase II project started.”

“ In late 2005, I was dispatched to Japan for a joint R&D project, for several months, and after that task I came back and involved in the design for the Hongyan River Project.”

In the Hongyan River Project, which was a CPR1000 nuclear power plant after the break through gained in the Ling Ao Phase II project, Mr. G was positioned in the Nuclear Island Engineering Division (NID) of CNPDC. At that time CNPDC was placed under CNPEC in order to shape a lump sum contractor.

“ It was in the Hongyan River Project, I first learned what is indeed engineering design for a nuclear power plant. Scientific Knowledge does not equal to the capability of engineering design.”

“ In the months in Japan, I became aware of what is R&D.”

“ From 2006 to 2008, before I was dispatched to JDO in France, specifically in the engineering design for Hongyan Rivier Project, our design job was in fact a duplication job. From my perspective, this kind of job has nothing to do with engineering design. We don’t even fully understand what engineering design means.”

“ Just now I told you that from the emergence of our team - nuclear island system engineering division - we are a group of no engineering design experience. Most of us, have not worked in a design institute before we perform the design for Hongyan River Project. We are consisted of the people who are fresh graduates, and some engineers who once worked in the Ling Ao Phase I and Phase II’s engineering design management, but not really design. More appropriately it is design review.

In the Ling Ao Phase I Project, those people attempted to do some engineering research, but not a systematic design for a plant."

" Only after the establishment of CNPDC, CGN has formed its own organization to perform a systematic design for nuclear island systems and the conventional island system."

Mr. G was the first batch of the engineers dispatched to AREVA in 2008 when the Taishan EPR project started. His held a dual position in the JDO. On one hand he served as the assistant Technical Manager to the Chinese presentative in JDO, and on the other hand, he worked in the design group in AREVA's system design team. "We dispatched 40 system design engineers to AREVA's French and German design teams. In the years from 2008 to 2011 approximately 60 system design engineers were dispatched in total."

" Before 2008 I really did not know what can be called engineering design and its role in the entire engineering project. I did not even know what tools and knowledge are critical for the design of a nuclear island system. As a summery I am not clear of the importance of engineering design."

" So from this experience I learned something. Regarding to building engineering design capacity, I think management is very important, because capacity building must have some strategic guidance. When CGN negotiated with AREVA and Westinghouse about the EPR and AP1000 technology transfer, the JDO was included as a major theme of such technology transfer project. In this respect, out top management has realized what capacity building is, so that CGN intentionally and systematically dispatch people to the AREVA's design system to learn from them. As a consequence, those who participated got some in depth understanding of what is engineering design and what is engineering design process, and even what is engineering design management. The JDO covered a wide range of our engineering disciplines."

" Each job descriptions about the JDO positions depicted what was the role of the designer, and his or her corresponding capability. The organization of JDO required detailed planning. At that time CGN's experts concretized such a planning. This is critical. The 180 designers dispatched to JDO were the seeds planted to AREVA's land. Later these seeds took roots. After that, we were transplanted back to the land of CGN. Now we are still nurtured by CGN, but some are given more care while others may receive less attention."

" My two years in JDO, can be termed as a capacity building by means of learning by doing. Capacity building can be achieved by practicing, not just for the sake of learning without doing. You know in our language, xue xi can be interpreted as learning and practicing or exercising."

Mr. G then quoted some Confucius' words about learning and doing to express his understanding of capacity building. "xue er shi xi zhi, bu yi yue hu" - "Studying is tough, while practicing is happy." "Studying the knowledge is tough but when you use the knowledge to solve problems it turns out to be happy. When you practice you may gain some feeling, and such feelings reflect enhancement of your skills."

" My position was very important in the JDO. Firstly, I was in charge of the RCP system. It means the entire nuclear steam generation and heat exchange system, not just the Reactor Coolant Pump. It includes the steam generator, the pressurizer, the piping and the pumps. And some control units. Secondly, I also took some responsibility of design management. Therefore, there were a lot of discussions about my tasks in the negotiation of the contract."

" AREVA and CGN hold different understandings of equipment and the system design. So I performed both system design and some equipment design. In this respect, I am a little bit of a hybrid. For a system designer, I make SDM (System Design manuals), issuing calculation notes and also sizing catalogues. Taking sizing for example, my understanding for sizing is more profound than Mr. A's (a technical manager of NITT on the AREVA side). His understanding of sizing is superficial. My understanding of sizing includes the sizing parameters in the functional requirements and the mechanical sizing in detailed equipment specifications. Mr. A's perception stays at the level of manufacturing specification. The clarification of sizing requires a lot of calculations before it can be issued to the manufacturer. A system designer is a synthetic person. According to what I have heard from EDF, the grown-up of a system engineer takes 10 years' time. This person is required to shift from varieties of positions. In the end, this person can finally be placed to the position of system synthesis. So when I did my job as the designer of the RCP system, I became quite aware of the safety issues of the nuclear power plant, the reactor engineering, the digital control engineering and the equipment. I needed to interact - setting up interfaces - with them voluntarily. So as a system designer, my design is a design of the process and at the same time, I do some job which should be done by the digital control people. This kind of job shifting or synthesis in CGN is relatively blank, because we normally think a system designer should not tap into the digital control field etc."

" Digital control is not just making instruments. Its logical analysis requires the system designer to draw a logic diagram to express its logical relationships. The system designer has to know and express the operational conditions. This knowledge is in the minds of a system designer."

“I spent nine months, to deal with these matters related to digital control and I spent another four months in the general layout team in AREVA as the deputy technical manager of nuclear island layout design. In that four months, I was also learning by doing. In the end I got a better understand of the process, not the design process but the understanding of operation. The most impressive thing that I have learned is that I find the expression in design is quite important. Each phase of the process requires an effective expression. Interfaces are manifested in these expressions, so that the results of the different disciplines can be synthesized to create a system. I had a clear understanding of this, as the deputy technical manager. It is the RCS (Reactor Coolant System, here equal to RCP system) designer, who can be familiar with so many disciplines, rather than only one area. For example, the equipment designer may only concern about pumps or valves while I need to know all of them.”

“The process of working on the layout design is tough, because in AREVA doing is more loaded than studying. Learning combines studying and practicing in AREVA. But this sort of learning is not comprehensively tutored in the sense that someone will come and help you to do the work.”

“I overcame this difficulty by myself. Basic technical knowledge is very important for my own capacity building. I search on the internet of the design manuals from a variety of engineering disciplines. At that time, I found that there were plenty of related design manuals which could serve as the references of nuclear power engineering design, such as the hydrodynamic testing and calculation models and the related pressure vessel design in the chemical engineering. The most amazing thing that I found was that in AREVA almost all the system engineers kept these references handy. But in CGN we do not have such a systematic reserve of all these. All these manuals are heritages of the western people including Russians, while in our university education, although we know the basic principles, we are not taught in such details of how to use them in an industrial setting. These manuals are the valuable knowledge of industrial application.”

“The JDO provided me with a platform, in terms of a design system, that made me realized what a system designer need to do. But after knowing that, I need to build up my own capacity in order to fulfill that job. In AREVA’ you are freer to source information from various channels, but what is more important is that the predecessors in AREVA have already made plenty of accumulations in the sense that the library in AREVA is better established.”

I discussed some topics in the interview with Mr. M to Mr. G. I said that from Mr. M’s point of view we are now facing a similar situation to AREVA’s in the 1970s when they entered into a technology transfer contract with the Westinghouse. Mr. M told me that CGN is in a better situation in terms of knowledge accumulation compared to them at that time. Mr. G made a joke saying: “Sure. Because we buy the technology after them, and we have done it twice.” Here he meant that before the NITT for EPR technology transfer there was technology transfer contract called TT95.

Mr. G said: “I feel that the old engineers in AREVA are more willing to help us, because they can understand our hopes and desires of mastering the technology. In the past they have similar experiences when they were learn from the Westinghouse. But the younger engineers in AREVA are not so supportive. Someone has even made it bluntly that if AREVA teach CGN all the technical secrets, how would they make a living? So in the JDO our engineers played a competitive role with the French peers. Some CGN engineers are asked to do some pure labor work, or boring jobs, not technically important tasks.”

I said: “That is not what we want to do”

Mr. G replied: “Definitely not. Sometime fierce arguments appeared in the work place in JDO.”

“ But under that situation, in our Chinese team, we made some efforts to accumulate knowledge. We exchanged what we learned from our jobs, in regular manner, in our internal meetings. We recorded what we learned in reports, in documents. We organized seminars every week in our dorms.”

I asked: “When did you return?”

Mr. G answered: “I got a new position in the NID in 2010 and therefore I came back.”

“ My job changed a lot when I came back from JDO. I mainly focus on doing in CNPDC, not learning. I was asked to participate in a number of on-going engineering projects, as you can imagine not just the Taishan Project, and some R&D tasks. But I was given a higher position, so my views for engineering design changed. In that respect, I need to say that I have learned something anyway.”

“ In AREVA I mainly concentrated on the basic design of the Taishan Project, but when I returned back to NID (Nuclear Island Design Division), I faced a lot of problems derived from the detailed designs of several projects. Still there were some problems related to the construction and commissioning of the on-going projects and also some problems of equipment manufacturing. As a system designer I need to make analysis of whether some non-conformances of the manufacturing to the design would impair the functional requirements of the system. In these three years, I gained more detailed experience on solving site related engineering problems. After the Fukushima accident, I encountered engineering problems that aimed to the improvements of the already built units such as the add-up of a high positioned water reserve for Ling Ao Phase II units. I felt that what I accumulated in JDO, the methodological knowledge and the understanding of the design process, helped me a lot in the problem-solving of these improvement designs and other site related detailed design issues."

" After I came back as the chief engineer, I am in the position to organize capacity building for my fellow engineers. I think that I have a clearer picture of what kind of capacity is required in my team. So I organized a cross disciplinary capacity building across different branches in my division. I identified capacities according to my own standard and motivated people who were willing and suitable to participate. My standard derives from my experience gained in AREVA. I compared the stereotype of a system engineer in AREVA to ours, and found out what is missing in our organization. Then I intentionally triggered some sort of a voluntary capacity building campaign. This attempt lasted for 3 years, from 2011 to 2014 before I left NID."

" Our duplicative engineering design can be regarded as an OEM activity. In that design, we just need to make sure that the result of AREVA's original designs are completely copied. But in order to do some original work of our own, we need to carry out some capacity building. Later in our projects, we have made some changes of the equipment which means new problems. AREVA cannot always help us in such matters. These problems push us to solve problems on our own."

" In the post Fukushima era, we have decided to add up some new non-active safety systems to the new build and old plants. This is done entirely on our own. We believe it only us who did this. But in order to realize these improvements, in addition to design, testing is required. We have a lot of pressure on the development of these technical improvements."

" It is a very broad concept when you asked me about the design process. I think two key points are permeated in the design process: first the functional analysis and second, safety analysis of the entire system. The first phase of a design is to clarify the functional requirements of the system, and then the system engineer can start to assemble a system with pieces of equipment such as the heat exchangers, pumps and their accompanying electrical instruments. After that the detailed designs can be distributed to the disciplines such as civil structure design, equipment design, electronic design, air condition and ventilation design etc."

I said: "Here the interfaces come."

Mr. G. Said: "The system designer works as the synthesizer. The system designer needs to use the appropriate engineering language to make the engineers from different disciplines working together. For example we need to justify that the feasibility and compatibility of requirements rose from the rector engineering calculations and then to interpret them to the follow-up disciplines. These tasks are done in the basic design."

I asked Mr. G about the R&D activities and non-nuclear power projects in the NID.

He said: "The high position water reserve project is the first big R&D project heads by CNPDC. It is a demonstration project sponsored by a governmental agency. In NID the R&D projects are nuclear related, unlike the conventional island division which may be able to get some projects related to solar or wind power, our knowledge and expertise restrict our scope of work. In the NID we once got some non-nuclear related projects such as the radioactive material containment design for petrol chemical companies."

I then asked him whether the experience gained in these projects would benefit capacity building.

He said: "Those engineering projects do not reflect the feature of nuclear power engineering design. Civil engineers working in CNPDC may use their expertise in nuclear projects also in other engineering projects. But engineering design capacity building in CNPDC requires a focus. Nuclear technology can be used in the chemical engineering, because petrochemical engineering is also an engineering of a reaction process."

I asked: "who are more restricted? I mean in CGN, what I have seen, those equipment designers and civil engineers seem to be more restricted."

"Yes, I would not deny that. But as I said this is based on the trainings that I have received. I think it consists of some knowledge of the reactor vessel and some knowledge about the safety analysis. As far as I know people in AREVA are not system designers from the beginning. There is no discipline called nuclear island system design. I know someone in AREVA who is a engineering physicist. When he entered AREVA, the organization, the system pushed him to accomplish the work. AREVA provided him with necessary methods and guidance to fit in his job and shaped him to be a system designer. I heard that it cost him 2 to 3 years to accomplish this transformation. But I think we cannot accomplish this in CGN."

I asked: "Do you think it is because that AREVA has a broader definition of the scope of the work to an employee while we have too narrow definitions to our engineers?"

" I think it is a matter of the system, of cultural difference. Their technology development is standing up on their predecessors' shoulders. They keep systematically their experiences and knowledge. Scientific, technological and methodological knowledge are all well documented, and looking into their industrial codes and regulations, they are more consummate than ours."

" In addition, their methodological documents are much more detailed than ours. For example when I first entered the JDO, I received a manual on how to write a proper internal email. The manual has 5 pages. When I first arrived, I sent emails without titles, this was deemed as extremely inappropriate in AREVA, but quite normal in our company. I was amazed to receive the manual on how to write an email including how to make the title and how to organize the content. This is an example about how detailed their methodological documents look like."

" I felt ashamed that I was not good to act properly. This indicates what we need to do in our own capacity building for engineering design."

" This is what I mean a proper methodological guidance to nurture new engineers to make progress on the past experiences. As such systematic improvements of technology can be achieved."

The above is the record of my interview in the first day. It stopped by a phone call asking me to perform another task related to the NITT project meeting. This interview was done from 6pm to 7pm April 15, 2014.

On April 16, 2014 I found another interval in the NITT project meeting to continue the unfinished talks.

I first asked him to describe his daily activities in a normal day in CNPDC to make some connections between what we have discussed the day before and the new discussions.

" Previously before I went to France, I was a senior designer in the division. My task was mainly to give reviews of the documents. Another part of my job was to attend different meetings. I got orders from my superiors from the meetings and I coordinated among different groups and divisions to clarify their scopes and intentions. After the meeting I brought the orders back to the team, and started making new documents."

" In France designers attend fewer meetings. Every day I calculate, make documents. I call to my colleagues as a kind of normal communication, but, very few meetings. I cannot make assignments for other people. I simply do my own job. So I have more time to think and to do some concrete work."

“ In China, normally we rely on meetings to solve problems. It takes up to 50% of my working hours. Here as you know, we are either the coordinator or being coordinated.”

“ After I came back and was appointed as a chief engineer, most of my time was used on attending meetings. In average I attend more than one meeting per day. The numbers of emails once increased to 300 per day at the maximum.”

I asked: “What are the contents of the emails?”

Mr. G answered: “Some of the emails are for information only, but some are tasks.”

“ In my busiest days, on the post-Fukushima project, as I mentioned yesterday, I received about more than 100 emails for this topic. But I had no time to reply.”

Mr. G then asked me how many emails that I have per day. I said: “About 30 to 50 on average.”

He then said: “Now working as the NITT technical manager, I receive only about 20 emails every day on this topic. That is good.”

I turned the topic of commenting on our situations to a new topic of whether R&Ds can be perceived as a form of engineering design.

Mr. G said: “No, they are different. R&D needs us to look into the future, while what we call engineering design here means an application of what we have already known. It needs to be practical. Engineering design requires some skills to make sure that what is designed can be implemented. But R&D, as I see, is theoretical, aiming to provide some sort of an alternative of problem solving. R&D cannot rely on experience, but engineering design must rely on the knowledge and experiences that we are certain. Engineering design must rely on verified experiences.”

“ As I see, ACPR1000 is an engineering R&D. It is a partial innovation.”

I asked: “Do you thinking innovative R&D project is a good mechanism of capacity building?”

Mr. G answered: “No. On the contrary, I think only CNPDC are equipped with a better engineering design capacity, the better chance CNPDC are likely to succeed in innovative engineering R&D. R&D is not an engineering design capacity. Engineering design aims to make a project successful after a testing based on the already established methods. If the project is successful, it means the ability to make applications of the knowledge is acquired. On this basis, some attempts of making changes to what is known can be carried out."

" R&D cannot be the final destination of capacity building in CNPDC. CNPDC, from its establishment, is a design institute not a research institute, not CNPRI. R&D allows failure while engineering design does not allow that possibility. In fact, I think our CNPRI is doing some R&D jobs for technology localization. Their work is based on AREVA's design. They perform some verifications according to Chinese industrial regulations and technical codes. Therefore it is a transplantation of technology from France to China."

" The difference between CNPRI and CNPDC can be expressed from a disciplinary perspective in the sense that CNPRI focuses on reactor vessels and nuclear fuel assemblies while CNPDC focuses on the entire plant. CNPRI also provides operation and maintenance services such as testing and sample analysis such as equipment qualification and experimental verification by scientific methods. It is not what CNPDC should do. In some sense CNPRI is an organization similar to EDF's research institute and the French CEA's basic research units. Making computer programs for scientific calculation is a part of their job. AREVA is an end-user of these services. CNPEC and CNPDC shall act like AREVA by leaving these R&D tasks to CNPRI."

I said: "I see capacity building actions in CNPEC and CNPDC rather scattered. A lot of actions can be regarded as for capacity building. What do you think is the best way to channel capacity building in CGN?"

" I think it must be an action both on the top and at the bottom. For example the NITT contract is the company's strategic plan. But the signature of the contract brings about a question of how it can be implemented. Those who really need the improvement of capacities are those who work at the fronts. When these prerequisites are met, a question comes: how to make engineers participate voluntarily. First they shall find out what kind of capacity are lacking, and then make some efforts to overcome these shortages. In the divisions of CNPDC such kind of identification of capacity shortages has been carrying out for years. Those who stand at the fronts know what they need but perhaps their leaders are not quite sure. Some of our divisions make clear goals of capacity building but some divisions are blur on this matter. Therefore, the capacity building actions varied and scattered in CNPDC."

" I think we need a plan which is clear and feasible for capacity building. But currently we don't have it."

At the end of our discussion Mr. G once again emphasized the importance of methodology.

He said: "Methodologies need to be accumulated, need to be taught, by predecessors, tested and verified. In those ways followers can use these methodologies to make different results. But the situation is that the average working experience of CGN employees is quite short. Therefore, we lack experiences. We lack methodologies."

I said: "CNPDC has issued a lot of design manuals which can be regarded as methodological documents. Are these design manuals issued by translating AREVA's files?"

" No. We need to make a lot of things by ourselves, because they contain a lot of experiences which are gained in China over the years of localization. They require verifications, without verifications such manuals are useless. Right or wrong cannot be judged without verifications. Methodology is the same. When it is applied in different situations the results may be different."

Finally I had some discussions with Mr. G about the management of engineering design capacity building in CGN.

First we made a consensus that in order to avoid repetition – in terms of human resource and financial inputs – we need to make our project experience documented so that the followers will not start from the beginning again.

Second, we shared a view that capacity building cannot be turned into a sort of a management system. In that situation these actions will be rendered into superficial jobs in the sense that they become a work of making documents and records regardless of knowledge accumulation. The number of documents cannot measure the content and usefulness of knowledge.

Mr. G made his final point on capacity building: "Now we have so many interfaces when we are doing design. It is in fact a result of the division of labor and the requirement of expertise shaping. At the beginning we don't have so many people. Therefore, many types of jobs have to be done by one single person, but in that case the quality performances varied. But when the division of labor becomes narrowed jobs seem to be narrowed as well. At this moment we need to combine some overly narrowed jobs, and in this combination process the transfer of knowledge become very important. This may be a solution to the problem of interfaces. The obligation of knowledge transfer is what I have experienced in AREVA. When a technical document was issued I was required to upload a series of supporting document on to the server, such as the calculation notes, the references, and the questions identified from the review process and their solutions etc. This is what I call a knowledge transfer inside an organization. It will keep the knowledge remain in the organization rather than keep making old knowledge."

Appendix C. Interview with Mr. M

On April 14, 2014 I interviewed Mr. M in my car on the way to a restaurant where decided to have a dinner together after a whole day meeting.

This interview was not taped. It served as my initial attempts of asking for his opinions on CGN's engineering design capacity building, in order to make a formal interview with him. I kept the notes in one of my notebooks after the dinner in order to record what I heard from him. The formal interview took place on April 15, 2014. The interview on April 15, 2014 was tapped.

Mr. M has been working in AREVA for 38 years, and now is serving as the NITT project manager - my counterpart on the AREVA side. Back in the Framaton years, he participated in the technology transfer between Westinghouse and Framaton, when the French started to develop their own nuclear power technology under the American support. He acted as a nuclear island system designer at that time. In the late 1980s he participated in the Daya Bay Project and in the 1990s the Ling Ao Phase 1 Project. Since 1995, he acted as the technology transfer manager on the AREVA side for the implementation of a series of technology transfer contracts between AREVA and CGN, including the most recent NITT dedicated for the transfer of the French third generation of pressurized water nuclear power technology (EPR technology) to CGN. Before 1995 he was first trained as nuclear island system engineer in France, when nuclear power technology was a rather new engineering discipline in France back in the 1960s and 70s. He got the job offer from Framaton even before he graduated from his last academic program. He was employed as a system design engineer and later was sent to Westinghouse in order to learn nuclear power engineering as a part of the technology transfer project.

As he could remember the development of nuclear power technology in France as it was in the America and also later in China, derived from a political determination of transforming the nuclear scientific research from the military ends to civil use.

He made some points as we talked on the road on April 14, 2014.

First, he said that engineering design for a nuclear power plant is very specific. He did not explain what he meant by specific, but I deduced what he meant. A Nuclear power plant is a construction project of an infrastructure, therefore, due to geological, and climate features of the site, each nuclear power plant even named under the same trade mark, such as EPR or AP1000, is not exactly the same. The minor differences represented in the design are normally called design modifications to the reference plant or the prototype design.

Due to the specific nature of the engineering design for a nuclear power plant, it means that even under a technology transfer contract, the licensee of the contract will have to solve some engineering problems in the design process by itself. The licensor may be able to give advice but the work has to be done by the designer of the particular plant itself. This is the experience, from his point of view, share by both Framaton and CGN.

Thus, as Mr. M pointed out, the “judgment” and the “construction” of engineering design capacity shall be based on the performances of the design work, in other words the real projects.

However, after emphasizing the importance of the specific nature in engineering design, he quickly mentioned another point, in his original terms, “in order to improve engineering design, it is also important to find a partner so that the partner can provide alternatives of solutions on the specific problems”. “We are obliged to help you, as we entered into the TT contract.” he said. This statement indicates that AREVA is now the partner of CGN’s engineering design and its capacity building. In this respect, engineers’ cooperation on problem-solving can be founded on a commercial basis.

Knowledge played an important role in engineering design. Mr. M emphasized that CGN should keep the knowledgeable person stable in the organization in order to maintain its capacity and to enhance it. He later explained what he meant by stable:

“First, those who are technically trained by AREVA shall be kept constant to do technical jobs when they return back to China, in CGN, rather than some other types of jobs such as managerial and administrative tasks.”

“Second, those who are knowledgeable shall not be money making oriented”. On one hand, the company need to provide the engineers with better payment, on the other hand, the people themselves shall not sell their knowledge for a better price in terms of finding another job when they realize that they are technically more capable. Instead they shall persist on using their knowledge for the sake of further technology improvement in CGN. He later admitted that this was a complicated question.

In the dinner we were making some casual talks.

One of my superior asked Mr. A (one of Mr. M’s colleagues) a question, after knowing that Mr. A is good hand ball player and now still playing in a semi-professional hand ball club in France.

“Do you earn money from the club?” asked my supervisor.

“Yes. But a little. We get some trophies when we won.” answered Mr. A.

“Since you are a good player, you should get paid to play.” said my superior.

After this discussion about the professionalization of sports players, we knew that in fact Mr. M is a good bridge player with some kind of a ranking.

Mr. M played for fun as he admitted and Mr. A made similar expressions in the course of the dinner.

One question appeared in my mind: “Are people getting engineering knowledge only for the sake of money, in China?”

I did not raise this question on the table, but I could guess that all the people might have shared the same question mark at that moment because, I saw my superior felt reluctant to explain the current situation of Chinese professionalization of sports.

After the dinner I drove Mr. M back to the “Expert Village” in Daya Bay. The Village was built in the 1980s when the Day Bay Project was under construction. It is used to accommodate the French engineers. Now, it is turned to be a hotel, for short term visitors. On the road, I made the appointment of a formal interview with Mr. M and he gave me the last suggestion of engineering design capacity building at that night.

He started his statement by making a sound with his figures: “Capacity does not come like this. It needs the accumulation of experience, and engineers need time to grow up.”

The formal interview with Mr. M was performed on April 15, at noon, when we finished the morning section of the NITT meeting.

I started our talk by giving some general summary of our discussions the day before, and then led the theme of discussions to the development of CGN’s engineering design capacity from a historical perspective.

I first brought up the topic of TT95 - an older technology transfer contract - which is also headed by Mr. M. The contract was signed in the 1990s when CGN started to build its Ling Ao Phase I and Phase II power plants.

However, Mr. M thought that TT95 was not a good example of engineering design capacity building via the TT. He indicated that the EPR NITT was a better example of engineering design capacity building via the TT contract.

He said: “TT95 is just training, that means, you have the right to ask what you want. But if you don’t ask, you seldom get anything. The contract has been signed for nine years, and just one year before the contract is about to finish you start to raise questions. Because you find that oh, I signed the contract, and I don’t have anything, and now I want to exercise it anyway. That is why you asked but limited. After that you said OK, we have to extend this contract for 10 more years. But you know in any case it was just to answer the question you raised. What we need to supply in the TT 95 are mainly some documents. And it is also very limited. We transferred one code or something like that. But it has nothing to do with the Taishan TT, where we have a scope of supply anyway - the lump sum scope, the additional scope through Work Orders. But in TT 95 it is only a Work Order scope. You don’t get anything if you don’t ask questions in the TT95. So for me TT95 is not a good example of TT. It is not an actual transfer of technology. It is very limited compared to the Taishan TT.”

Then I wanted to direct the discussion to a broader topic not just the TTs. Therefore, I asked: “Can you give me your opinions about how CGN grow from Daya Bay to its current status? about engineering design” I thought Mr. M as a witness of CGN’s development, and I told him this. Therefore, I wanted him to tell me what he witnessed.

“ For Daya bay, I remember, the capacity, you tried to get some knowledge through the review of the documentation of the NIEP contract. Since we have a formal review of the documentation that means according to the contract there were a lot of technical documents that were transmitted to you for review and for approval.”

“ That means we send the documents to you and your engineering raise questions officially. We are obliged to answer you and until you don’t say no. The documents that we sent to you, either you don’t have any comments, and you put Acc that means Accepted or you say, accepted with comments and you send the comments to us. We provide the answer and until you don’t think it is not clear for you we still continue the answer.”

“ I would say that through the contractual review process of documents. You get some basic knowledge about our design. Because the contract was write down like this, people you know, people in your team foresee this process of document review would bring in some knowledge. For example the procurement files of the main equipment and some basic studies for core design. We were subjected to answer your comments. Until you accepted these documents, this process continued. I would say that this is the first step to acquire knowledge through this process.”

“ That was the first step to acquire competency from our design. First step. Important.”

“After that, what happened?” I asked.

“What happened was that we provided some training for you, but that was limited compared to the NIEP. You pushed the localization of activities. That was very important for the Chinese industry maybe. But I would say that you want the design activities to provide jobs for the Chinese companies. So we are obliged to perform localization.”

“Even in Daya Bay?” I asked.

“ Maybe in Daya Bay it was very limited. Some piece of equipment I don’t remember. What we experienced in Daya Bay was the failure of the C23 Company in the erection of the nuclear island equipment. EM2 was always in our design but all the other EM packages were for the C23 Company and, in fact, they failure. That caused a big problem in China, at that time. It was ANP got another contract, an additional contract that performed these EM activities on behalf of the C23 Company.”

“I don’t know this; I have not read it from our records.” I said.

“ You have to remember this. Such kind of failures had impressed your leaders. That is why for the others, your decided from the beginning, you require technical assistance from us. We send people in your team. All the commissioning activities, which seemed that you were responsible for, you asked for key people from ANP to be included in your team. That was the first wide corporation and trust that we both started. And it was because of this integration of ANP into the technical assistance in your team first in the commissioning of the Daya Bay plant and the later entire Ling Ao Phase I Project which was a big success. These people once participated in Daya Bay and Ling Ao Phase I are now almost retired and thank to the trust of ANP, it was a success.”

“ From Ling Ao Phase 1, I am sure that you were responsible for the commissioning. Even for the erection not for the EM2, EM2 was always the scope of AREVA. But all the other EM packages you were responsible for and obviously there were a lot of ANP people in your team, and that create you know a good corporation between our two companies. All these people when they are talking about AREVA they always say that they remember very well. Move back to the topic of design, all the people integrated in your team raised the level of your team. And now you can manage by yourself.”

I then, switched the topic to the design of Ling Ao Phase II project, in which the design even though was largely a duplication of AREVA's original design with limited modifications, changes, was done for the first time by Chinese designers.

Mr. M made his comments on the design of Ling Ao Phase II as such:

"We know that the design was not entirely a copy, with your own changes, but what I feel is that you lack a basic design, while it is true that you have the detailed design."

Then I asked him about the differences between the basic design and the detailed design.

"I would say in term of the detailed design is, for example, the drawings of civil work and the flow diagrams of the system and something like that. But even in the detailed design, you just have the outputs which are needed to the design of civil works that could be use on the site, and the system design manual etc. But you don't have the inputs which are ahead of these contractual documents. Such as the methodological documents, which are about the basic design documents. But even in AREVA, there is no such basis design document."

"You mean even for EPR design?" I asked.

"No, for Daya Bay, the methodology is created for the EPR, before that it was in the brain of some people. That is why yesterday, I said that if you have some capable people please kept them in the company. Because, for a very long time more than 20 years, AREVA we don't have methodological documents. It was in the brains of some people, but by chance or not by chance, we kept all those people in the company, most of them. You know what I mean?"

"Yes, you mean the knowledge remained in your company." I said.

"Yes. That is why it is important for the future of your company, to work out some methodological documents for the new tasks that can be done."

"Thanks to the TT negotiation, it was discussed in 2003 when AP1000 and EPR were in the bidding process. AP1000 and EPR were in competition, AREVA promised a lot of methodological documents which does not exist by then. And now thanks to the contract, we are now obliged to work out them through the NITT."

"All the input data, the input deck, for example the FSAR (Final Safety Analysis Report), all the data to reach to the result you don't have for Daya Bay and Ling Ao. So that is the reason why for Ling Ao Phase II when I discussed with the NPIC (a sub-contractor of the design) manager of core physics. He was very concerned that they had to duplicate but they did not performed the studies. Now thanks to the NITT, no problem, you will have all the things."

"That means we can do the same kind of things as you did." I said.

"For the duplication principle now you will have all the things. But if you have all the things you can think, how AREVA do like this and that. You will learn a lot. When you have all the things, you can think why all the data are worked out, and you learn a lot."

"What do you think of the JDO?" I asked.

"JDO is a good thing. The best way to learn is to doing some job within a certain time because now you are obliged to work."

Then we discussed about an example of the JDO trained engineer, Mr. G. Mr. M thought that he was well trained and became more aware of the things than the previous engineering manager of NITT.

"That is why I say to you the best way to learn is to be obliged to do the job. He (a designer) was involved in such a detailed design job. But to do a detailed design you have always a basic question about the reason why. And obviously when you do detailed design you learn something about the basic and conceptual design. So JDO is a good thing."

Mr. M said "I now need to make an inquiry. Where are all these people? The NIEP people (on the AREVA side) told me that some people who were trained in the JDO are now not working for the EPR project. You miss a lot of things by doing like this. These people will forget something, or they might leave the company in the worst situation. But after five or six years they move back to the design work they will have lost some knowledge. You have to keep these competent people in a growing curve in term of the load of work. In this case they will get better and better. That is also a project management concern. To choose the good guys and put them again and again on the technical positions."

"Well, people can change the things they do, but I believe that they are the people who like it. I have experience when I entered ANP in the 1976. A guy met me on the first day, and said to me hi, and me too. This guy was kept in the technical department, and now he is an expert. He always likes technical job. If by chance you met some guy who likes technical things, please put them technical. Don't make them a manager or something. But obviously it also has something to do with the benefits and make them feel that their job is important."

I then told Mr. M that it was quite common in CGN that our engineers felt technical jobs normal, and after several years of working they might feel tired.

“That is a problem of the management. You cannot make the people who always do the same thing. You have to make a bit change. And you have to make them responsible for more and more important tasks. Obviously, if you make people to make drawings and system design manuals, say for two years, people will say I am feed up. You have to think about the career development of your technical engineer. Not let me always sit on the very limited piece of job. When you select smart people, you need to let them increase the scope. Let them in transverse activities. That is important, otherwise you will keep nobody. To have a specialist to do litter things, that is a problem. That may be a problem of thinking about the work in your company.”

I want to find some solutions of this problem, by asking Mr. M how ANP is solving it. I find this problem varies obviously in different companies. From my interviews; it seemed that my company is not solving it effectively. It seems that career development for engineers in our company is to become managers, rather than keeps in the track of the technical team, even though the company claims to make enough space for technical engineers. Then I asked Mr. M a straight forward question: “Do you think that AREVA is doing better in this matter and how?”

Mr. M made the following statement: “We have rankings in our engineering teams, level 1 and level 2 leading to a specialist status. And we consider the mobility of people by promoting them from one kind of engineering to another or from engineering to purchasing based on their own willingness. Their personal willingness is well concerned. Now in our company, the human resource in my company may think that if people change job in every three years it is a good thing. Personally, I don’t think so, but now it very open to make changes on the people according to their wants. The people have to take themselves in charge. They have to know what they want to do. But people have to feel that their concerns are recognized by the management. Now we evaluate people every month, every year, or maybe every two years, if they are considered as very promising people, the human resource tries to propose these people specific possibilities.”

“We don’t have such a proposal scheme. We are waiting to be chosen.” I said.

“We have but in the evaluation you have to prove that you are a very capable person. Our evaluation is based on the feelings of the direct manager of the guy. The manager have a lot of guy and he have to make an evaluation of the guy at least once a year. The evaluation is done in two parts: one for the salary and one for the capability. We have a matrix to rank people with A B C and this result has some connections with the salary, and it is reported to the human resource. If the guy raises a quest of changing a job, the human resource can propose opportunities. But anyway the basis for this is that people should take themselves in charge, they have to decide what they want to do. ”

I asked Mr. M about CGN’s outreach of businesses to other realms of engineering projects, and its effect on the engineering design capacity building.

Mr. M answered: “I think such kind of outreach is based on the fact that you have known the key factors in the processes. For nuclear engineering it’s the organization of the process of how to do something. The basic for project management is how to organize the processes, for example the necessity of make some channel exchange, interface exchange, and how to work out the interface. If you have such kind of thinking of doing one kind of activities this basic principle of organization can be adapted to other activities. For me through my experience, the key is to have a good organization of the work, methodological documents to have tools, for example IMS (information management system) project procedures. Those are the keys which imply a lot people’s skills.”

“When we were doing Daya Bay and Ling Ao, all the people were working in the same tower, the AREVA Tower, including Sofinel (AREVA’s Design Institute). So it was easy to communicate; now it is too scattered. We have people working in Germany, and people in France, and even in France we had many offices. Sofinel is not in Paris. Can you imagine?”

“And the split of work, who is in charge of this and that, when you do it like that you multiply interfaces by 10 by 100. If you cannot manage the interfaces you will fail. You will be in delay. From my own experience, for me, but it is off-record, the delay of the EPR is the result of the interfaces. Too many people working together, and too much split of the work. There is a lack of organization and procedure of how things to be done. That is my personal feeling. That is why for the management, a good organization should have sound basic procedures. If you solve these fundamental topics you will be able to succeed.”

I raised a question about the national feature of the split of work in engineering design in China and in France and its effect on engineering design capacity building. Because the difference of the split of work will be manifested as the difference of the scope of design, for example something that CGN thought as the design work is what AREVA termed manufacturing.

“ Frankly speaking for the equipment in AREVA, there are some equipment engineers who work out specifications and general drawings. They foresee the general design of the equipment. But for the detailed design, we have the manufacturers in the factory who develop their own knowledge about how to do something about welding, the material and performing test. The basic knowledge and detailed knowledge of our manufacturers is very important and sometimes, they reflect their opinions on the general design in terms of suggestions. They foresee the materials because we have experiences also in order to promote modification. They provide a lot of modifications for prolonging the duration of the equipment and also they reduce the cost. So I think we have the chance in AREVA to have this complementary design knowledge for the equipment. Obviously in the AREVA tower we don't manage in the detail of all the things which are involved in the manufacturing of the equipment. For us it's a good thing, because I think our manufacturing now is very efficient and very good."

" We don't have a factory in CGN as the manufacturer of the equipment. So how can we claim to have some improvements of the design of the system without knowing the advancement of the equipment? That is the question in my mind." I said.

" Yes, yes that is what we can avoid in AREVA. When you decide an improvement of the design, you may failure due to the lack of manufacturing knowledge." said Mr. M.

" Obviously, in our factory there is some testing, to test the possibility of achieving the design. For me it is difficult to perform equipment design if you don't have any experience of manufacturing. It is a risk to require something which is not quite feasible."

" What you have just said is also some sort of a consensus in CGN. Now our main equipment design engineers are sitting in their office making drawings and doing calculations. These are fine but it is also a concern of how to give our engineers more experiences on the manufacturing." I said.

" Yes, but those activities do not equal to make a good design of the equipment. It is just the justification I think. Seriously for me, most of the improvements, that is typical in Daya Bay, Ling Ao phase I and Ling Ao phase II, you are always making improvements on the Steam Generator. If you look into the detail, it was thanks to our factory. Ah yes. It is difficult to be equipment designer if you don't have a daily experience of the manufacturing yourself."

At last Mr. M made an example of the Toyota motor to illustrate the improvement of design based on the manufacturing practices.

Appendix D. Interview with Mr. L

Mr. L is a young man who was educated to be a mechanical engineer in the university. He was employed by CGN in the year 2007 when he was just graduated from the University with a bachelor's degree. Now he is taking a part time study in mechanical engineering for his Master's degree. Mr. L first job was in Shanghai, in one of CNPDC's subsidiaries. Then he shifted from Shanghai to Shenzhen where the headquarter locates.

I knew him in the year 2008 when he worked as a part-time coordinator of NITT the technology transfer in his division - main equipment design. He was appointed to a technical leader of the design of pressure vessel internals in the year 2009. Their object of design is some mechanical parts inside the reactor pressure vessel. These mechanical parts will support the reactor vessel and help the control of the reaction. Mechanically the internals has a strong connection with the fuel rod, and consist of the inside structure of the reactor vessel. He thought the appointment to be a promotion. Over the years he keeps working with me on the NITT technology transfer.

I gave him an interview asking him about his daily engineering design work, and his perceptions of engineering design capacity building.

I recorded the discussion with a tape recorder, but something happened to the battery of the tape recorder. So only half of our conversations were tapped. The recording of the other half of our discussion had to be done by my notes. Therefore, the second part of this interview is rendered into some kind of a transcript of my own words on what he said.

Mr. L is quite supportive to my studies on engineering design capacity building. I once organized a group interview in his division. He actually helped me to organize that group interview and being an informant in the questionnaire surveys that I developed in the early stage of this PhD research. It is from those general studies of the overall picture of engineering design in CGN and on the people's perceptions about capacity building I found it quite necessary to give him a face to face, interview.

I started this interview by asking his understandings of the "nuclear power plant system" because I found that not every designer had a picture of the system in mind in their daily work, or their understandings of the system might be partial, in the sense that the mechanical designers regarded the system as an assembly of machines. The system designers treat system as heat and hydronic exchange processes.

This would impact their interpretations of their own scope of work, and importantly on what engineering design capacity means to them.

The first sentence Mr. L made in this conversation was:

“Nuclear power plant is a complicated system.”

Then I asked him what consists of the nuclear power plant system.

“The nuclear power plant system consists of its sub-systems, we call units. Every unit has to perform its functions so that the entity can be made. The entity is the system.”

“What did you do as a designer in CGN in a typical day of work?” I asked.

“I think my normal day of work can be described as consisted of some sort of chaotic events. Considering the time that I spend on using different computer software, the outlook email is the most frequently used software. I spend half of my day using it to communicate and to coordinate. Maybe it is because that now I am a group leader. So I have many things to handle with every day. Some of my group members are now working in the factory solving some site problems. I also have to lead some R&D projects and certainly some real design activities for the on-going projects. In addition the NITT project in my team. I also have to play some management roles - managing people in my group. I feel that I have less and less time to perform real technical work.”

“What are the real technical work refers to?” I asked.

“My understanding of real technical work is performing some technical analysis and do some research. But now I feel like that I am doing an engineering management work and going far from the real design. But it does not mean that it is not good. I hope that I can develop the capabilities of my fellow group members, so that they can play my part as I used to play. Some of my peers are very keen on doing technical work. If I do too many tasks by myself, I will be too tired, and it is also not good for my group members. They need opportunities. So I think I am quite open to give them more tasks. In this respect, I have less and less concrete technical jobs to do in my daily work.”

In the office, we heard the music started to play. It was a piece of music for a kind of a physical exercise break, of which we were getting used to since we started our education in the primary school. This music is played in every Chinese primary schools, middle schools and universities. In the university it is the sign of a morning exercise, but here in CGN, it offers a voluntary break in the afternoon.

Mr. L closed the door; it looked as if he would not want to have a break in this conversation.

“Every day the first thing for me is to give a review of what has been done in the previous day, and check whether somethings needs me to report and follow up. I start to dispatch work to my group members immediately after this review. Another important task for me is to coordinate. Such coordination takes a large amount of my time, because we cannot solve every problem on our own. We first need to be clear of our scope and the scopes of others.”

“When I find there are some tasks that we cannot do in the group, I need to find someone in CNPDC to do them. When someone would not accept the jobs, I need to report to my superior. When the division leader cannot push the agreement, I need to find the chief engineer of a project to allocate this job. This takes up to 50% of my hours. Therefore, a lot of my time is used in writing reports and sending emails which I think is some sort of a coordination and management work.”

“Another part of my work is to motivate my group members. I assign the work in the group, and when the work is finished those who accomplished it require some compliments. They need some feedback. In my position, I can not only act as an information or work hub, I need to provide some guidance to my peers. As such it will facilitate communication.”

“The rest of my time is used on what I call real technical work.”

“For me, designs can be classified into several categories. First the R&D related jobs, such as the design tasks in the ACPR 1000 (now HL1000) project. In detail, we get some input and based on our scope of work, we work out some calculations, and perform some verification. In the end we lead to some conclusions and these conclusions serve as the input for follow up engineering disciplines. Or the conclusions may support the next phase of our own design such as the detailed design, in terms of making manufacturing drawings and assembly drawings.”

“The second part of our job is to support manufacturing factories, in case the manufacturer raises some questions which require further interpretation. Some questions derive from the misunderstandings of our drawings and some from the non-conformance report (NCR) discovered by our surveillance people. NCR refers to the inconsistency of the manufacturing with the design documents; it normally represents a manufacturing problem but not a fatal mistake. Testing and evaluation are required by the designer to decide whether this non-conformance can be accepted according to the technical standard and the functional requirements.”

The recording stopped here. It was before the start of the next interview I discovered this problem. Therefore, the following part of the interview is presented according to my notes.

“ The third part of the technical work refers to some supporting work to the site problems which happen in erection and installation. Some equipment may be scratched during such activities. Therefore we need to send our engineers to the site to evaluate whether such slight damage would impair the function of this mechanical part, and do some testing on whether it causes risks to its duration etc.”

After hearing Mr. L described the technical work he is involved every day, I feel that it is in fact a mechanic perception of nuclear safety.

Then I asked some questions in order to make him clarify his perceptions of the knowledge used in his job.

The first question I asked was “How to define a good design from his disciplinary perspective?” and the second was “Will the knowledge about the system be useful to improve the design of main equipment?”

His answer to the first question was quite clear:

“ In my view, our job is to design good products, in terms of good seismic resistance feature, and long term duration in operational circumstances. Therefore, we focus on the materials, and their mechanical properties and their fatigue analysis. In order to ensure the stability and completeness of the equipment we focus on the structural effects of our machines. We cannot make mistakes because if our products fail, it will have a big problem. Unlike the system designers and the safety analysis people who calculate safety risks on a probability study, we cannot rely on probability study. So risk does not mean anything to us. Our job is to make sure that our products will still be able to function even in the most severe accidents.”

Mr. L compared the design of the AP1000 reactor vessel to the EPR, and said: “I think EPR has a better reactor vessel. AP1000’s reactor vessel is rather old. AP1000 may be advanced in its safety systems but when we look at the design of the reactor vessel it has nothing radically innovative. What I can say here is that the EPR reactor vessel has solved more mechanical problems in its design than the AP1000.”

In fact he answered the two questions at the same time.

Mr. L also made his point on the rotation of jobs among different disciplines.

“ I don’t think the rotation of jobs is going to be helpful for engineering design capacity building. Capacity building needs to have a purpose. If after a round of rotation I am still appointed as the equipment designer, I will think it is a waste of my time. Because, the system knowledge only serves as the background of our design, we can learn it by ourselves. We don't need in-depth knowledge of the system unless we find understanding the input data difficult. I think it is better to have a narrow split of work in our company so that people can focus. The methods and tools used in other disciplines can be very different. In equipment design we don't need their methods and tools."

Mr. L is quite a straightforward person He made some comments to the engineering design capacity building management issues in the previous focus group interview that I performed in the previous year.

I asked him how he was appointed as the group leader because I felt him quite a leadership oriented person. At the same time he also seemed to be disciplinary oriented in terms of knowing how to develop his own expertise and career. I was curious about how such a technical people was chose to a group leader which might reflect some ideal type of "personal capacity building" in CGN.

"The promotion to the group leader is a surprise for me. Because at the time when I was promoted, I had only been working in CNPDC for 3 years. Normally, in our division the promotion to a group leader is based on the following criterions: Experience, in terms of how many years the person has been working in CNPDC, and education background (major and degree). If these criterions were constant I would never be chosen. My advantage is that every time when I receive a task, I try to think about the expectations of my superior. And he once told me that every time when I accomplished the work, in most cases, the result was beyond his expectations."

"Does it mean that your products are better than the others?" I asked.

"Not the quality of design but the quality of work in general." He answered.

He did not make further interpretations on what the quality of work he meant, but from his later words I might be able to conjecture.

I asked him some questions which I found interesting from the discussions in the previous interviews - the question about interfaces. I asked Mr. L about how the interface is defined in their work. He gave me a physical example:

The bolt used to fix a piece of equipment is an interface. In the nuclear power plant construction the bolt is often embedded in the concrete. The screw cap is something that is used in the installation work. We, as the equipment designers, need to consider the fix of a machine. Selecting both the bolt and the screw cap is in our scope. When we choose the bolt, this data becomes the input for the civil work engineers and they have to express it in their civil work drawings. The control of the positional deviation of the bolt is in the scope of the civil engineers, but we are responsible for the physical liability of the bolt. The positional information about the bolt becomes input data for the following erection work.

I asked Mr. L the question which was pointed out by Mr. G about better ways to interpret system design results to engineers in different disciplines.

Mr. L said: “As I see that we have a formality problem in our drawings. Each group has its own style, the fonts, the method of making notes etc. Putting these drawings together, people will question whether they are made out by one company except the logo. AREVA is doing quite good in this, their styles and formalities of drawings are identical. They have a specific drawing team, but we don’t have one. Our drawings are made in the groups. But the diversity of styles and formats will not cause problems because we are facing with different manufacturers. The manufacturer for one machine does not need to read drawings for the other pieces of equipment. But I still think that the format and style should be identical.”

Appendix E. Interview with Mrs. S

Mrs. S is a 45 years old female civil structural engineer. She was educated in the South East University in Nanjing China. Her university is one of the well-recognized universities of engineering especially in Architecture and Civil engineering. She was educated to the bachelor's level. She has 22 years of working experience always in civil engineering design. At the beginning she worked in her home town after her graduate from the South East University in a mineral mining engineering design institute for seven years. In the late 1990s and early 2000s she thought southern China would provide her with more promising career development opportunities. She decided to move to Shenzhen with her husband a mechanical engineer also a graduate from the South East University. She joined ARUP - a well-known civil engineering design and consultancy firm - in its greater China branch in Shenzhen. She mainly worked on normal civil engineering projects before she switched to CNPDC in 2008 when CNPDC started to form its civil engineering design division. She was employed by CNPDC as a specialist in civil engineering design.

I worked with Mrs. S in the Joint Design Team which was consisted of AREVA's subcontractors in civil engineering detailed design IOSIS and CNPDC. The basic civil engineering design for Taishan nuclear power plant was done by AREVA. But AREVA lacked the personnel and the expertise in its detailed design. Such kind of steel structure design and the drafting of its reinforcement drawings have to be subcontracted to other suppliers. In this case, CGN pushed AREVA to make CNPDC a localized civil engineering design sub-supplier. As a consequence, the JDT was formed by IOSIS and CNPDC engineers.

In 2010, Mrs. S was appointed as the technical manager of JDT and I was appointed by chance as the commercial manager of this task.

The major design tasks in JDT were to transfer the basic design from AREVA into shop drawings which are going to be used on site in Taishan. The basic design was rendered in sets of calculation notes and some handmade rough drawing. They are basically some general ideas of the steel structures. The drawings have to be made according to the Chinese technical standards, thus some changes of the calculations and the formality, and even the choice of materials have to be adjusted accordingly. JDT's drawings had to be sent to AREVA for final approval because AREVA as the basic designer had to take the technical responsibility.

The JDT detailed design tasks have been completed, in 2013. The JDT was dismissed. After that due to her successful and fruitful work she was promoted to be a branch leader (higher than the group leader) in his division.

This interview with Mrs. S was done in April 25th, 2014. She let me use her office to perform the interview with Mr. L. I arrived at 2 pm. Mrs. S was in another meeting. Mr. L happened to be free. So the interview with Mr. L took place earlier than Mrs. S. In fact, Mr. L was in waiting for an evaluation meeting for his own small R&D project encouraged by CNPDC as a self-development project. The company provides funding for these R&D projects. On that day, it was something like a defense of Mr. L's R&D report.

My interview with Mrs. S took place at around 3 o'clock, when Mr. L had to finish his talk because he received a phone call from somebody who told him that it reached to his turn to defend his report. I also experienced similar situations in CNPEC. Such kinds of evaluations of the young engineers' small R&D projects were a form of peer review in the CGN system.

I started the interview with Mrs. S by asking her to give a comparative review of her daily work in her previous design job and the job in CNPDC.

" In my previous job in the civil engineering design companies, my tasks were largely technical. Although I need to work with different technical disciplines and attending the meetings organized by the owners of the projects, these meetings took only a small part of my time. About 80% of my time was used in my technical tasks, such as calculations and making drawings."

"Could you specify your technical tasks?" I asked.

"I make plans and blueprints for the building structures, and verify their validity. Based on the comments from other disciplines - my colleagues - I need to make modifications on my plans and blueprints. These are what I call the technical tasks. I calculate based on numerical analysis; I issue drawings and reports. These tasks directly reflect my own perceptions on engineering design."

"Ok, I understand, these were the designs you did in your previous job." I said.

"Yes, from a sequential perspective, I first make an initial general plan, and then I perform calculation, after that I make drawings with affiliated reports. I seldom perform the so-called managerial tasks. If there are any, these tasks refer to organize technical discussions among different disciplines. "

"When I joined CNPDC, at the beginning, I felt a tremendous change on my every day activities. I even cannot make a clear illustration of what I did every day, at the beginning."

“ Well I can now depict what I need to do every day.” I said to Mrs. S. At that moment I felt the same about the change of jobs here in CNPEC from my previous job.

“ Before I was appointed the director of this branch, as you know, I worked in the JDT as the chief engineer, the technical manager. But it is a project organization served for the sole purpose of one single project, the Taishan project. It was not a typical working day in CNPDC, a typical day for a CNPDC design engineer consists of different activities for different projects, and fulfilling a lot of administrative orders. All these activities are simultaneous, thus the day looks like a chaos. JDT’s job compared to the typical day of a normal CNPDC engineer’s is more focused. It was a specific task.”

“ Now my days are filled up with different technical tasks for different on-going projects, some R&D projects, and some specific meetings such as the quality assurance meetings etc. The situation that one engineer participates in two or three tasks at the same time is quite normal. In general too many meetings take up my hours. These meetings can be classified into technical meetings with related disciplines, progress report meetings to my superiors - to the divisions - and to the project organizations etc.”

“ The time that I used to study technical standards, performing calculations and participating in technical discussions with my colleagues becomes less and less.”

“ So, how can I make a summary of my job?” murmured Mrs. S.

“ Another part of my job is to reply emails and writing reports. I feel that most of my time is used on either attending some meetings, or preparing for those meetings. As far as I know, a lot of our engineers live and work like this.”

“ So it seemed that a lot of people are performing managerial jobs.” I added.

“ Yes, now my position becomes quite unique, in the sense that no matter what the issues are, I am obliged to take part a meeting for whatever it is about, technical or about people.”

“ Do you think it is due to the fact that there is an over split up of our jobs in CNPEC and CNPDC, that leads to too much meetings?” I asked.

Mrs. S answered: “I think it is a feature of nuclear power engineering, because it involves too many people and too many disciplines for just one purpose. For normal civil engineering projects, less engineering disciplines are required. There is a huge cost of communication induced by such a huge number of interfaces. This is a typical feature of nuclear power engineering."

" Do you think that you are now having an abundant knowledge about nuclear power plant's systems?" I asked.

"No."

"But still, you can do your job." I added.

Mrs. S answered: "I kind of know something about the nuclear power plant system. But I certainly don't know all."

" I have a feeling that nuclear power plants for you are just buildings, in terms of concrete and steel structures." I added.

Mrs. S answered: "Not exactly, we need to know some basic parameters of the system for example the seismic classification of equipment. And we also have to know some data from the operational conditions. We need to perform our calculation and simulation according to the definition of accidents, such as the basic design accidents, or severe accidents etc. We have to get a feeling of what is a normal accident and what is a vital accident. Technical standards used in the design of the structure vary upon these conditions. However, the design for a nuclear power plant can be referenced to some normal civil engineering standards. In nuclear power plant design, we need to know the calculation methods stipulated in the technical standard for different accidents, and the verification methods. Otherwise, our calculation cannot be done."

" We need to know the cause of the problem, and then we can start to perform analysis. Hence we can find solutions for the problem. This knowledge has some relationship with the system design."

" Another reason that we, civil engineers, need to know something about the system, is the civil engineering design to prevent system broken down in the airplane collide scenario. We need to know which part of the system needs to be protected. These parts cannot be impaired in case of an airplane collide. Especially, those parts that will cause a stop of the reaction, and the heat release, and the parts that protect the used nuclear fuel. The protection of these parts of the system is critical for our design. We need to know the principles of the system design, in order to conceive the protection strategy, so that the consequence can be avoided. The nuclear power plant's redundancy layout is important for us, because, as long as we make sure that at least one complete train of the safety system is not impaired, our goal is achieved. This has something to do with the system design and the layout of the entire plant. But when it comes to the details of the hydro-thermodynamics and the heat exchange, it is out of our scope. Anyway we know the logic of the system design."

Then I turned the topic to the so-called engineering design in a "forwarded" direction in contrast to the reverse engineering, which became a new focus of transforming the fashion of engineering design in CNPDC.

Mr. S said: "Now engineering design in a "forwarded" direction becomes an important mind set in CNPDC. In my own words, such kind of design means a design process from a concept to a structure, from making plans, to the calculation of the operation conditions, and hence to the structure. We have to understand the above mentioned principles before we perform this sort of design. Previously, in CNPDC, we started with a result. We know that the result is a good and verified result. Therefore, even if the designers cannot construct the plan and understand the principles, an acceptable will come at the beginning. But now in the mode of a "forwarded" direction, we need to start from the concept."

"Have you experienced a period of making duplications of the drawings?" I asked

" When I came, I started from the detailed design of the EPR, thus I did not experience. As far as I know in the later CPR1000 designs, some improvements emerged and these improvements were in fact some engineering design in the normal direction, because in these designs the logics of the original design needed to be re-constructed, so that the changes could be substituted according to the logic of the original design."

"For the intermediate design documents, we are now trying to construct our design methodological documentations, especially when we face improvements, modifications, and design changes. I think that now we have gone through the design duplication designs. We now have a complete process of a normal design. But if this new project is not to be finished we cannot claim that we have acquired the capacity to perform a nuclear power plant design. Corporation between the interfaces is very complicated in this sort of "real" design. The corporation between the disciplines will experience a process first at the general level then into the details."

"From the studies of engineering design, we see a relatively clear demarcation of the design phases such as the conceptual design, the basic design, and the detailed design. But just now you told me that in real life engineering design in CNPDC such phases are not clearly split apart." I said.

Mr. S said: “Yes, for example we need to exchange data in the PDMS system. At a certain design stage we need to make some input data into the system indicating the status of design. Thus the configuration management in the PDMS is quite important to reflect the overall status of design. We need a real project to figure out how this configuration management of design can actually work. It is not just that we learn this configuration management concept from AREVA in a course and we suddenly find that we are capable of doing that. ”

“ When you retrace the experience in JDT, do you think such kind of working together with IOSIS was beneficiary to our designers?” I asked.

“ Yes, it is good for our capacity enhancement. When we work together with IOSIS, it is the first time that we make a real design which leads to the issuance of shop drawings. Thus, in our new R&D project, I am not worried about making shop drawings by our own engineers. I believe we have already acquired such kind of capability, and now it is only a matter of how to diffuse the knowledge of these capable people to the entire branch. We have already known the process of making shop drawings and the tools.”

“Is that to say that knowing the process, the methods, and the tools mean you have acquired the capacity?” I asked.

Mrs. S answered: “Yes, but only one person knows these do not represent the capacity of the entire team. The team must know all these and that represents the success of capacity building.”

“ You also have experience in the so-called joint design. What is the difference between the French organization of design and our organization of design? I got some reflections. They told me that due to the fact that our definition of disciplines is too narrow, our project communication and coordination becomes complicated. What do you think of this opinion?” I asked.

Mrs. S answered: “As far as I know, the French style of engineering design organization has more integrated arrangements than ours. For example they have an integrated layout team; therefore all the interfaces about the equipment and buildings are dealt within this team. But in our organization such layout team is dispersed in different divisions. Therefore, when we discuss problems about the layout, each layout engineer represent the interests of their own divisions. Thus, for me to minimize conflicts in the interfaces, the organization structure becomes the most important factor. We need to consider which organizational structure provides the best efficiency.”

“In that case, it will reduce the amount of time spent in the coordination?” I asked.

“ Yes. For example in our ACPR1000+ research and development project, we solve such problems not at an integrated higher level like the French people. We solve these problems at a lower level, between the divisions, that reduced our efficiency. We need a decision making at a higher level of engineering, and this indicates the competency of the leader of such a layout team. He or she must be an experience team leader. Now in our organization, even at the lower level, there exists the same problem. Who is going to make a decision when all the participants seem to make sense?”

“No decisions?” I asked.

Mrs. S answered: “No, no decisions from a single person. Therefore we must rely on the so-called collective decision making. Collective decision making is not always effective and efficient.”

Mrs. S picked up her phone, to answer one of her colleague.

She continued: “I think the feature of nuclear power engineering is that too many disciplines are involved. So communications and coordination are necessary. We are a state owned enterprise; therefore we need to make a lot of reports, multiple level of reporting. We are redundant in terms of management. The matrix of management is a two sided coin; it has both the good side, and the bad side. Both the project and the administrative management influence the design, one more train of management. This is our company’s feature. Experience is also very important in the decision making. If experience is lacking, asking a big group of people to take part in one meeting is a waste of time.”

“ How many percent of your time is spent on what you called technical tasks versus the managerial routines?” I asked.

Mrs. S answered: “30% on technical tasks and 70% on managerial routines.”

“What is this 30% consisted of?” I asked.

Mrs. S answered: “Technical discussions or meetings to perform collective decisions.”

“Meetings again?” I asked.

Mrs. S answered: “Yes, plenty, every day we receive plenty of technical questions from the site. Just before I came to have this interview with you I was in a meeting about the sizing of the holes on the concrete walls.”

“ There is another feature of our company, the administrative manager and the engineering manager is positioned on the single person. Everybody is involved in both the technical and the managerial discussions.”

“ If the managerial and the technical job are separated, will that also cause redundancy?” I asked.

Mrs. S answered: “In fact, I prefer the engineering people solve technical problems, leaving the managerial people solving human resource and other problems about the people. There are plenty of problems about people.”

I picked up a drawing on the table and ask her whether she is signing these drawings as approval.

Mrs. S said: “I am not signing now. I need to read it. I sometimes need to give some serious thoughts and comments on it. Otherwise, I will not know how to evaluate my staff. How difficult a problem the person is handling. What kinds of competencies are reflected from the solutions. Through the reading of the drawings I will be able to make my judgment of my staff’s capabilities, technically. If I leave these technical jobs to the chief engineer, I cannot manage my people. I cannot distinguish their talents.”

At that moment, it appeared in my mind that Mrs. S seemed to have a clear definition in mind that management equals to solving problems about people, while those problems which have nothing to do with people or what can be dehumanized shall all be treated as technical.

Therefore, I asked her to clarify of what is design management, which is also a word that we often use in our organization, but nobody really knows what it really means.

She gave me an example on the making of a drawing production plan, saying that the control of scheduling and input data and the reduction of the mistakes served as the key factors of making such a plan. The making of the plan itself, is a design management activity in which efficiency matters. Regularity, the prediction of productivity and the real production rates are also mattered.

I feel that, in fact project management is a kind of technology in CNPEC.

And then I would like to know from her the entire civil engineering design in a nuclear power plant. Therefore, I asked her about the split of the civil engineering design work in her division. The division consists of serval branches, namely, the nuclear island building structure design branch, the conventional island building structure design branch, the geological study branch, the overall architecture design and site planning branch.

Among these branches, as Mrs. S thought, her branch is the most important.

As she said: “In our design, we need to comply with the nuclear industry standards. But in the structure design for the conventional island, normal civil engineering standards are enough. The nuclear power industry standards are technical higher demanding, on the resistance of vibration etc.”

I asked her further about the relationships and difference between civil engineering design for nuclear island buildings and the normal civil engineering buildings by making a question as the following: “Do you think your previous education and work experience before CNPDC are useful in your design of the nuclear island buildings?”

“Yes, sure.” She said, “The essence of design is always the same.”

“What is the essence of design?” I asked.

“The essence is the analysis of the load-carrying capability, and the properties of the materials, the concrete and the steel. When we figure out the stress and load distribution of the structure, we can work it out. Force and the properties of materials are the essential elements of design.”

I then asked Mrs. S a question on whether she met some problems of the interpretation of the drawings to her engineering partners. She said: “No.” But this answer contradicted with our later discussions about what is engineering design experience.

After this topic, we had a break and my recorder was running out of power. Thus the following description of interviews is made according to my notes.

Since Mrs. S has said many times about the importance of engineering design experiences in performing a good design. This reminded me to ask her what experience is, because in other interviews the word experience seemed empty for me.

Also I got confused about one question: We signed the technology transfer contract with AREVA, and AREVA committed to transfer us all the methodological documents. If all the knowledge about the methods and the result of the design is transferred why would our engineers still complain that AREVA is hiding something from us?

Is there something more than knowledge that is important to improve our design?

I asked Mrs. S a straightforward question: “What is experience?”

She did not answer me directly, but she gave me some examples which represented a lack of experience in the design.

The first example is the sizing problem that she discussed in the meeting before came back to her office to attend my interview.

She said: “This problem derives from the so called ‘habits’ of our design. Normally the sizing of the holes on the floor plates is regular in our previous designs. It depends on the sizing of the bolt which would be fastened into the hole in order to sustain the weight of a pipe and the cables inside it. No one has questioned the sizing and its impact on the load carrying capacity on the floor slab. Because we know the sizing of the holes is small so that it won’t bring about a problem. But this time we intend to put more cables inside the pipe thus the hole is required to be larger, and now someone raises the question on the load carrying capacity issue, whether such a larger sizing of the hole will impact on the stability of the floor slab. If we have not calculated the case of large sizing, we need to start the calculation from the beginning, which is a time consuming job for this tiny problem. But if someone have the experience, the decision is easier to be made.”

The second example is a problem of when to start a detailed design of a steel structure inside a room in the nuclear island building. In the basic design of the nuclear island building such designs for internal steel structures shall remain blank, it is until the layout designers and the equipment designers who finally decide the size and weight of the equipment and the layout designer give the initial drawings of the room, the civil engineers start to perform the steel structure design in order to support the equipment and make its maintenance feasible. Previously when CNPDC was doing some sort of duplication designs, such problems of when to start the detailed design never happened. It is now in the R&D project that it becomes a question because neither the equipment designer nor the layout designer can at an early stage provide the input data required by the civil structure engineers, because the equipment design is not finished yet due to the lack of feedback from the manufacturer. The machine is not a regular machine which is already manufactured, but requires the manufacturer to make some modifications of the design in order to finally decide its shape and size without jeopardizing the required functions. In such a case, it brings in a chain of problems. Even though the basic design can be done by providing some functional requirements, without a detailed design, the construction cannot be performed.

The third example is in fact a mistake happened in the reading of the civil engineering shop drawings. In Taishan project, on the steel structure detailed design drawings some oval circles were drawn. Such oval marking is intended to tell the constructor to make exactly oval holes on the steel beam. When these holes are filled with bolts, the stress of such connections can be released. But what happened on Taishan site was that in one steel structure, all the holes were made into perfectly round holes, thus the stress of the beams and the bolts cannot be released as it was intended. The constructor said that they misunderstood the oval marks as the tolerance of the round shape. Since they could make a perfect round shape, such an oval shape on the drawings shall be disregarded. In fact, if some words can be added to the oval marks such a misinterpretation of the drawings can be avoided. But unfortunately there were no such words on the drawings indicating that the holes shall be made intentionally oval not a tolerance. Mrs. Sheng said: “Experienced designers would add words on because they must have experienced similar events. But it is hard to say if it is a mistake of the designer or not.”

I learned these cases, on Mrs. S computer when she showed me pictures from the site.

At last, she concluded: “Experience comes from details. Knowing the scientific principles and the knowledge do not equal to a good design. A good design comes from practices and the learnings from mistakes”

Appendix F. Interview with Mr. W

Interviewer: “So shall we begin now? I would like to ask you some questions about engineering design capacity building. From the procurement and project management perspectives, could you identify some important factors of engineering design?”

Mr. W: “Well, engineering design capacity is first expressed in engineer’s synthetic abilities of systems and equipment. In both system and equipment designs, the designers will raise some requirements on the specific equipment to be procured. In real life work, we often witness some deviations from the design requirements, in the sense that the equipment on the market cannot meet the technical specifications of our design. In case such a deviation occurs, we need sound engineering design abilities so that we can find out how to deal with it. For instance if the manufacturer cannot build such an equipment or have to work under a tight time limit to provide the required product, it seems from a project management point of view a high demanding requirement which will cause problem on project progress.”

“The problem is when the equipment ready in the market cannot meet the design requirements, how can our engineers deal with this problem. If our designer lacked such an ability of dealing with these deviations, we have to ask the manufacturer to abolish its already built equipment or we need to change the sub-supplier. If this is true, from a scheduling control point of view, it will be an unexpected loss of the entire project.”

“This is a type of engineering design capacity, and this capacity is in fact a comprehensive awareness of the market. The designer has to realize that if their requirements exceeded the state-of-the-art of production technics in the market. The designer also has to know if their requirements indicate very limited suppliers which can qualify. This kind of capacity is very essential for us. We are not really doing high-tech products; we are indeed in need of those already industrialized and standard products. You cannot make each piece of equipment used in the nuclear power plant a product out of a R&D process. This is not only true in our domestic market but also in the global market. If even the European advanced suppliers cannot provide ready products that meet the design requirement, I would say that the design is not good at all. In that case the designer totally disregards the reality. As a summary of this point, I would say that the designer must have enough information about manufacturing technics in the market. The design should not be a requirement that cannot be met.”

“Another aspect of engineering design capacity that I would like to point out here is the understanding of industrial standard. The major industrialized countries adopted different industrial standards. The Europeans use their standard. And even within Europe, the French adopts its own nuclear power industry standard RCCM while the Germans use their KTA. The good thing is that in Europe there is a general manufacturing standard. In China, we have the GB standard and the Americans have their ASME. In such a globalized and diversified situation, considering nuclear power engineering design and its follow-up procurement by competitive bidding, if the standard is chosen to be only one without alternatives, the choices for procurement become very limited. This will lead to a limited number of potential sub-suppliers from which we can finally choose one. A lot of bidders are rejected because they are not familiar with the required standard of manufacturing. If the designers can understand all these standards the situation will be better. Industrial standard for me is a set of rules and procedures. It does not directly relate to the quality and functionality of the product. But if the designer is not familiar with the standard, he or she cannot make a judgment on the product, and its impact to the system."

Interviewer: "As far as I know, in China, we don't have a set of nuclear power industry standard up till now. Do you know that?"

Mr. W: "No, we don't have. Americans have ASME. In China we don't have an independent nuclear power industrial requirement (standard), instead of the general GB standard."

Interviewer: "As I read from our civil engineers' designs, the choice of industrial standard on nuclear power plant's concrete structures was an appropriation from the dam construction standard. In the standard, two requirements are listed, with one requires the endurance of 50 years, the other higher one required the endurance of 100 years. Since the designed operation of a nuclear power plant is 60 years, we have to adopt the 100 years standard.

Mr. W: "Yes, right."

Interviewer: "What is the situation in nuclear power plant equipment design?"

Mr. W: "As far as I know, in nuclear power industry we have to follow the GB general standard, and adopt the high standard instead of the low standard. But we don't have an independent system of the nuclear power industry. For example in the design of pressurized containers, the GB standard is the only thing we can refer to. It will bring some problem in our self-reliance manufacturing attempts. Due to the difference of standards, some technical and functional requirements have to be verified by asking the supplier to perform additional tests. In that case, we can prove that our designs and products can comply with the French RCCM standard for example. This is a bottleneck for our self-reliance manufacturing of the equipment with a French origin.

Interviewer: “Ok, I also discussed this question about standard with another colleague of ours. Just now what you said were largely from a procurement perspective. Since design is placed ahead of procurement in our projects' engineering sequence, what do you think the designers do? Specifically what kind of problems have they solved in our projects?”

Mr. W: “The designers directly limit the choices of procurement and predict the range of the price we are going to pay for each piece of equipment. High demanding requirements indicate fewer potential suppliers. Therefore, the price is going to be higher. In some cases, the supplier will be required to carry out some R&D activities before manufacturing. This will cause some unexpected prolonging of manufacturing. R&D is not something that we can predict. From my experience in our EPR project, we witnessed many times that due to our R&D requirement and additional testing and verification requirements, many machines and containers, valves, etc. had to put into tests again and again, and this had great impacts on our scheduling control. At this point, I think, if our design is more reasonable in the sense that the design is more correlated with the current state-of-the-art of the manufacturing, it will on one hand, reduce our cost, our time, and on the other hand raise our competitiveness.”

“Nuclear power plant's engineering design is a systematic design. The essence of this type of design is its systematic synthetic feature. Due to the fact that some equipment cannot meet its original functional requirements, a large scale of design modifications, adjustments have to be performed. This causes a lot of reworks. We have to abolish some already placed orders, or make additional orders to purchase more adjacent pieces of equipment, or change manufacturing factories etc. It brought about great pressures on our budget and scheduling etc. Design is a critically determinative factor. It is said that if the design is good, other work turned to be an easy routine. Designers are those who give orders; if they give a false order other people will walk along the wrong direction which deviates from the ultimate triumph.”

Interviewer: “Let us move back to our previous question about deviations. What kinds of methods are available at the hands of the designers to deal with these problems? any specific examples?”

Mr. W: “One method often used is to make a technical compromise in terms of a substitution. Nuclear power plants are designed to work properly for 60 years but there is some equipment which cannot last that long, say 30 years. For example according to our fatigue analysis some of the valves cannot reach to a service of 60 years. We have requirements not only for the valves' years of service but also their sizing and weight etc. In fact, to prolong the valve's service, the easiest approach is to make the shell thicker but this will increase its weight and larger its size. Due to the sizing and weight limits, some valves must be lighter or smaller. In this case a compromise is needed. With a thinner shell, the years of service can only be ensured, say 30 years. As a consequence, the designer has to consider its substitution in the in-service inspections. That is to say two values are needed to fulfill the plant's operation for 60 years. One new valve will replace the old 30 years after the plant's commercial operation. However, we must admit that there are always some problems which cannot be solved by this approach, in these situations the designer have to find other solutions."

At this point of the interview, Mr. W received an urgent call from one of our colleagues when he was just about to say something about another approach of problem-solving in engineering design. The interview had to be stopped for a while.

When he came back from his phone call, Mr. W continued: "Another kind of substitution happens when a different material can be chosen. But it is very difficult in our self-reliant manufacturing because using another material means to substitute an industrial standard. The RCCM material is very rare in China, because normally the metallurgy industry in China follows GB standard. That is to say additional tests on the physical property of a piece of metal produced in China have to be done before it can be justified as equivalent to the RCCM standard. Chemical components analysis is also required. As a summary we have to show an evidence that this piece of metal complies with all the specifications listed in the RCCM standard before it can be put into manufacturing. It is abnormal for a standardized manufacturing process because a normal process does not require testing as long as the manufacturer knows the grade and the brand of the metal, such as GB Q235B carbon steel. It is a huge amount of work when these tests have to be performed because building a machine requires dozens of materials. When the entire machine is design to be built in compliance with the RCCM standard, the manufacturer has to prove all the materials originated from the GB standard are all equivalent to RCCM. The biggest problem here is that the solution of these problems has no sense of universality, in the sense that if this supplier has performed such tests and then the other suppliers can be waived from the same tests. It is completely a case by case problem."

Interviewer: "How can we improve our engineering designs, since you have already identified their shortcomings?"

Mr. W: "I think improving engineering design, is a step-by-step process. At the current stage, we may not have very good approaches to make a quick change."

I reminded Mr. W to focus on improving engineering design, because I am afraid that he was going to shift our topic to how to improve supplier's manufacturing.

Mr. W: "I got a feeling that CGN engineers largely performed system design and lacked equipment design knowledge. The system designer focuses on flows and fluid mechanic. They seldom concern about structures, fatigues and materials. So from a CGN perspective, we need to nurture good equipment designers. On quick approach is to recruit designers with manufacturing experiences into CNPDC, or we need to tighten our corporation with our suppliers. As such the designers will get some first-hand senses on whether their requirements can be achieved in real life manufacturing. Now our designers do not have such senses, they often draft a plan first and then wait for manufacturers' feedbacks and corrections."

" I think in order to improve equipment designer's work, they must be equipped with more knowledge, and now, from my perspective, they are not equipped with enough knowledge. I have to admit that it is very difficult. We focus on system design and that is our core competency. So when you ask me how to improve our design, I would say that to work with our equipment suppliers and do some concrete detailed design work is very important. In fact the self-reliance project is a very good opportunity for us. We can work with our sub-suppliers and carry out some R&D together. This may be a short-cut to improve our design."

Interviewer: "Is improving engineering design a personal concern or an organizational matter?"

Mr. W: I think it is an organizational issue. From a personal perspective, engineering design capacity building relies on experience. But experience cannot emerge just from book learning. Without verifications and tests from a real life project, knowledge seems to be useless. That is the reason why I consider engineering design capacity building as an organizational issue. Now, I feel that CNPDC's engineering design capacity is relatively theoretical in the sense that it is not competent in dealing with the problems emerging in real manufacturing processes. So engineering design capacity building can be considered as system engineering. If the company can provide enough projects, experiences of our design engineers can be generated from them.

Interviewer: "Now I would like to ask a question about NCR. What is a NCR?"

Mr. W: "NCR is a non-conformance report issued by the manufacturers in case they identify some deviations of their products from the technical documents which stipulate the right procedures or specifications of their manufacturing activities. Therefore, these records need to be reported to the designers. This report includes a description of the incident, and a detailed record on the handling of this occurrence. In fact this report is a record of a deviation of the physical equipment from its designed intentions. In this report, testing data is also included especially when such data is shown not in the range stipulated by the design documents. NCR is a record whenever a non-conformance incident happened. If no NCR is issued, it means the equipment is manufactured 100% in compliance with our requirements. If in the manufacturing process a thickness tolerance is identified, for example the thickness is required to reach 5mms however after a gauging the real thickness is shown to be 4.8mms, it is a question of whether this thickness will endure the maximum pressure required by our design. Then it is followed by a series of calculations and verifications on this tolerance, justifying whether it still permits this equipment to be properly operated under such a pressure. All these measurements, calculations, verifications need a record. NCR is used to record flaws of the equipment, because even if it is mitigated, it is still a potential risk. There records are important for the future operation and maintenance activities. If there is an accident occurs during a nuclear power plant's operation, these documents can be used to diagnose its causes."

Interviewer: "Are all these NCRs going to be transferred to the operator of the nuclear power plant and the owner of the plant?"

Mr. W: "In our classification, NCRs are categorized into 3 types. The first type is called the I-category, internal NCRs. These NCRs are those incidents discovered by the manufacturers' themselves. And these flaws can be mitigated or turned to normal by normal machine work, such as polishing a surface etc."

"The second type is called the E1 NCRs, external category 1 NCRs. These NCRs mean that if they are mitigated, the functional requirements in the design can still be met. That is to say, for example, according to our calculation, thickness in 4.8mm can still ensure this equipment to endure the maximum pressure, that means its functionality is not impaired, and then this kind of flaws fell into the E1 category of NCRs. E1 NCRs are obliged to report to the designer but it does not lead to a compromise acceptance to this equipment. Acceptance of the equipment does not need permission from the owner of the plant. The only work the designers need to do when an E1 NCR occurs is to report that a review has been done and verify what has been recorded is true."

"E2 category NCRs mean that these flaws can never be mitigated. That is to say the owner of the plant has to accept the equipment with a compromise. But such a compromise shall also fulfill a set of prerequisites. First, the designer has to commit that the functional requirements in the design exceed the real operational conditions. Therefore, even with such flaws the design margin can still ensure operational safety. Second, through modifying other parts of the system or adjusting operational procedures, no incidents that may impair the intrinsic safety will occur. In any case, an acceptance with a compromise of the E2 NCRs means that the design requirements exceed the safety margin, therefore the equipment is still considered as workable."

"Let me give you an example for example the fatigue analysis. Sorry I confused the fatigue analysis which is a study with a manufacturing activity."

“ For example, the casting flanges. In our standard, small holes should not be detected in the casting flanges. But nobody can guarantee that there are no tiny holes in any casting pieces. When these holes cannot be filled with wielding, we have to accept these flanges with holes because we know they that will not damage the nuclear power plant.”

Interviewer: “Who make these compromises as acceptance decisions? Is that the designer?”

Mr. W: “Yes the designers issue a report to the owner, presenting their analysis and suggest the owner to accept. All the E1 and E2 NCRs must be attached to the equipment manufacturing completion report except the I-category NCRs. A list of the I-category NCRs is enough. E1 and E2 NCRs will be used by the end-user to perform their equipment management.”

Interviewer: “Just now what you told me was all about the deviations from the manufacturing side. The design changes from manufacturing feedbacks. There is another type of design changes which derive from the design side, for instance due to some system modifications, equipment design will also change accordingly. Are these changes called DEN (Design Evolution Note) in our organization? What is a NAR?”

Mr. W: “It is called a DEN. NAR is just a process. It is a commercial process, due to the fact that technical changes will impact procurement in terms of price and budget. NAR is in fact a notification of commercial changes on the purchasing contract.”

Interviewer: “What is the full name of NAR?”

Mr. W: “N is notification. A means acknowledgement. R means report. So NAR is also a report of record. Yes it is a report.”

Interviewer: “It seemed to me that designers are responsible for all these changes. They have to solve or at least acknowledge these changes.”

Mr. W: “Yes, sure. The designers have to ensure the functional requirements of the nuclear power plant being met in their designs. They don’t care about the real manufacturing technics used on the manufacturing shop-floors. They appreciate testing reports, which tell whether the functional requirements can be met.

Appendix G. Interview with Mr. F

I interviewed Mr. F when we finished our small project on the study of the knowledge structures of engineering designers which we thought might help to improve their engineering design. The study on CGN designers' knowledge derived from our understanding that knowledge – both technical and social – serves as the foundation of engineering design. This perception is shared by both CGN's engineers and the management. Therefore our study is granted and sponsored by a company research program dedicated to bring about some visionary suggestions about CNPEC's reform. When we finished the project and handed in our research report to the top management we decided to sit down and take some review of what we have done. In addition, I found it a good opportunity for me interview to Mr. F for my PhD research on the human side of nuclear power engineering in CGN.

I started the interview with a question asking him about his job tasks and their relationships with engineering designs in CNPEC and CNPDC.

Interviewer: "How can you describe your job and its relationship with engineering design?"

Mr. F: "My job is definitely related to engineering design in CGN. Where shall I start? my current job or my previous job?"

Interviewer: "I want you to give an overall review of your jobs in CGN."

Mr. F: "Since I joined CGN in 2006 my job has always been related to our engineering design. But it doesn't mean that I personally perform engineering design. I have always been playing a supportive role to our designers. I am a contract engineer dedicated to technical assistance contracts. That is to say, I purchase supporting services and documents from prominent foreign nuclear power engineering companies to help our designers to solve problems or review their work. Previously our design could be described as duplications plus modifications; therefore we need numerous references. In this respect, my job has been closely related to our design activities."

" Now I am in another oversea nuclear power engineering project, and still is a contract engineer. My job is still to support our design."

Interviewer: "Why do we have to purchase these supporting services? Is it because of the reason that we meet some problems that we are not be able to solve by ourselves or that we just need someone else to review our work?"

Mr. F: "Both."

Interviewer: “What type of the two services is more frequently procured?

Mr. F: “It is hard to say. From my own experience, in the preliminary studies phase, the major services required are reviewing, but in the project construction phase, more problem-solving requests are raised by our designers. In general, I think these two kinds of requests are evenly distributed.”

My interview with Mr. F had to be postponed for about one hour because he received a phone call from his superior asking him to carry on an urgent task.

Interviewer: “Let us continue our interview. Just now we were almost finished with the first question about your work and its relationship to engineering design. My understanding of this relationship is that in fact you buy in some knowledge, expertise, and skills to our company and such knowledge and expertise can be used to solve our own problems or help us to identify if there are some mistakes in our work. I would like you to say something more about your current work.”

Mr. F: “I am now a commercial manager for a big project even though it is still in its preliminary planning stage. I am involved in the project’s licensing process. In this stage, I am also asked to source supporting services related to the modifications of the software we are using, the P6 system. It is the tool that we are using to manager our designs.”

Interviewer: “P6 means Primavera 6 – the widely used project management software?”

Mr. F: “Yes. So it is to some extent supportive to engineering design, since you know the PSAR (preliminary safety analysis report) includes a wide range of chapters, almost all included, and it is one of the important activities of engineering design in CGN.”

Interviewer: “Yes, I know, the PSAR is done by the CNPDC people in their overall engineering design division. Can you describe your daily routine?”

Mr. F: “My daily routines include making telephone calls, writing some reports, answering emails, preparing power point slides etc. and meetings. These are my daily activities, but if you ask me about the content of my job, I can only give you a summary as: now I am performing the commercial related jobs for a nuclear power plant project. My tasks are largely those planning jobs. This is a highly condensed summary which can be specified into serval smaller tasks such as the making of a Lump Sum contract (EPC – engineering procurement construction) and its consortium contracts if any for instance. I also perform some analytical jobs such as I am now studying how we can achieve a better mechanism to balance commercial interests among the different parties involved in our new built power plant projects. This is very important in the drafting of a consortium contract."

Interviewer: "Do you think that you have been involved in a decision making process?"

Mr. F: "I am supportive to make a final decision. You should think like that."

Interviewer: "Have you ever got a feeling that your commercial work is to a great extent similar to engineering design as a form of decision making?"

Mr. F: "Sorry, I am not catching your point."

Interviewer: "Let me explain. I got a feeling that our analytical reasoning approaches are quite similar to that of the designers. For example we use quantitative models etc. and evaluating their work quantitatively. In this respect, I feel that we are much alike. We provide different choices and the decision is in fact derived from these choices or alternatives."

Mr. Li: "We are exactly doing like this. For example the choices of our consortium members, or partners in the project, are in fact based on our data analysis on their competencies such as their revenues and profits. There are a lot of things that we consider from a quantitative perspective."

Interviewer: "But I think there are some other jobs which cannot be treated quantitatively, for example the licensing?"

Mr. F: "The licensing? It depends."

Interviewer: "Since you are now involved in an oversea project, a CGN's investment project, what is the difference between the licensing process in China and the country in which the new power plant is about to be built?"

Mr. F: "The most important factor in the licensing process in an oversea project is the acknowledgment of design qualifications. But it is sort of a state level international problem. Now the Chinese government and the Romanian government are planning to sign a mutual acceptance agreement on the two countries' engineering qualifications, as such the licensing process can actually go on."

" But let us move back to the question about quantitative reasoning. It is hard to say that which task can be solved solely by quantitative reasoning but from as far as I am concerned commercial or planning jobs in CGN are relied on scientific management. For example our project management is founded on scientific management principles, the 9 areas of controls. Our company's management is constructed by its management systems, which are based on rational reasoning. So does the management of engineering design. It needs a system to organize our work so that it can operate smoothly. I think the engineering design management system shall be more rigid."

Interviewer: "You said that our job is less rigid. Is it indicating that our work contain more social factors?"

Mr. F: "Right. From my perspective the designers have to be precise, while for a negotiator, approximation and compromise are always needed for example the choice of governing laws for a contract. Each party favors that the contract shall be stipulated by the laws of its own country, but if everyone insists on their own wishes there will never be a contract. So the trade-off is to stipulate the contract on a third country's law. We encounter more social factors than the designers."

Interviewer: "Can you compare the difference between your experiences in CGN with your previous experiences?"

Mr. F: "Before I joined CGN, I worked for IBM. My work in IBM was customer service, but unlike what you might image, I seldom contact with people in that job. They uploaded their requests or questions onto a system, and what I did was answering them through this system. I did not have direct communications with them not in a face to face manner, but I did provide my service. After joining CGN, I think that my job has changed a lot. But in some sense I am still performing customer service in an indirect manner, you know. I now treat the designers as my clients, and I fulfill their requests face to face."

Interviewer: "Can you describe your personal transitions in CNPEC. I knew you were previously in the service contract branch under the PBE, but now your position is in the planning and development branch. What is the difference?"

Mr. F: "I transferred from the service contract branch to my current position in this year. Before this change I was in the service contract branch for 7 years from 2006 to 2013. This transformation of position is accompanied by some changes to the scope of my work. I used to source for services not only for project purposes but also for some general tasks, such as you know, our capacity building or management improvement and some supporting services for our R&D."

Interviewer: "Are you mainly dealing with the TT95, the Liang Ao Phase II PLP, and the NITT contracts, in the service contract branch?"

Mr. F: "Not just that, what you mentioned are those corporations with prominent companies, AREVA, EDF, Westinghouse and Bacthel, etc. But there were also some cases with smaller companies in terms of prestige in the nuclear power industry, such as the SHALL. This company was once our equipment supplier. Its product is too specialized in its own area; we need to cooperate with it to make a progress on one of our R&D project in the realm of electrical engineering."

"Now my job has changed. I am not doing service contracts anymore. It reminds me another meaning of the word contract which can be used as a verb. Now my job is to some extent in a preliminary phase of a nuclear power plant project. My job is to get a contract for CNPEC and CNPDC together as a lump sum supplier. I am contracting with a hope to get a contract for CNPEC and CNPDC. Market development people are ahead of my job because before my involvement into a contract negotiation we need to make sure that there is an opportunity. These people in the international or domestic market development departments are those who bring in new opportunities. My involvement is behind this phase, when a memo of understanding regarding to the entrance into a market has been opened. But anyway, I am now in a very early stage of an international nuclear power plant project. I need to prepare bidding documents which are based on our feasibility studies. I feel that now my vision is broadened. If I am not in a different position my vision will be too narrowed."

Interviewer: "I think I am familiar with you, we once worked together on the NITT and also a lot of other things. But I feel that there is something that we have seldom talked about in our company, for example our environmental consciousness. So I would like to ask you some questions about your opinions on our company's environmental consciousness and on your personal environmental concerns."

"Just now you mentioned that before a new project there is a market development phase, and I think that a nuclear power plant is an environmentally sensitive project. So my first question is what do you think of our company's environmental concerns in general?"

Mr. F: "I will answer this question in two aspects. On one hand environmental concerns can be reflected by our company's organizational culture. On the other hand, I would like to say something about our engineers' personal environmental awareness and activities in a general manner."

"From the company perspective, I think our company emphasizes environmental protection. It is a clean energy supplier. When you think about clean energy, that is environmental protection. As you know, we are not only developing nuclear power but also wind power, hydro power, solar power etc. But please be minded that we never construct coal or petroleum powered plants. Coal and petroleum power is far from the notion of environmental protection. Building clean energy facilities is our company's vision. In this respect, I would rather say that our company put a great effort in environmental protection. This can be reflected by our products. But as a business company we are not that deep green. I think our prorogation of environmental protection is performed in a relatively unperceivable manner. We are a clean energy provider, and we change the culture by our work."

" In CGN we recruit educated people. From my personal observations I think that most of us are environmentally awakened."

"From my personal perspective, I print on both sides of the paper. I use the printed paper as my draft paper. I seldom waste paper. I buy a fuel saving car and I care a lot about the disposal of my wastes. I think these are common environmental habits. But if you ask me about some advanced activities of environmental protection, I would say that I do not pay a greater concern on this matter. I merge environmental activities into my life. I do things that I can do. I go as far as I can to protect the environment."

Interviewer: "Nuclear power compared to solar energy, wind energy, is not that environmental friendly. What do you think of this topic?"

Mr. F: "The question has two sides. I understand that the essence of nuclear power engineering is its safety culture. I also know that perhaps the general public's image of nuclear power is influenced by its negative consequences of the reported accidents. As far as I know the risk of nuclear power to impair the natural environment is the radioactive release. But using uranium to produce electricity can also be regarded as an environmental friendly technology. Compared to coal and petroleum power, nuclear power uses very small amount of fuel. The major concern is whether we can control the risk. This kind of control is achieved by our scientific design, and regulated operation. If we can make sure that no accident is going to happen, then nuclear power is a very good sauce of power. Compared to the conventional ways of electricity production, nuclear power does not require a massive scale of mining."

Interviewer: "Are you a science streamed or an art streamed student in your high school?"

Mr. Li: "I think the most severe environmental impact of a nuclear power plant is not reflected by its commercial operation but by its decommissioning. The land used to construct the plant cannot be used for other purposes. It becomes a dead concrete dome. And this status will last for a very long time, 100 years maybe. The land will be a waste land. This is the only bad thing I can point out on nuclear power technology. For other matters, I think that, as long as we can control radioactive releases, nuclear power technology in general will benefit our society. By the way, I am an art streamed high school student."

Interviewer: "Did you ever participate in some environmental protection organizations?"

Mr. F: “No. but I did participate in some volunteer activities. For example, when I was a student we volunteered to clean the streets. I think you must share the same experience with me. It is not an organization but it is certainly an activity. I did participate; I can only say it like this.”

Interviewer: “Let us move our topics back to engineering design. What kind of design do you think is a good design? On the other hand, what do you think is lacking in our design in order to reach this goal?”

Mr. F: “If you take engineering design for a nuclear power plant as consisted of a series of system designs including its subsystems, the result of designs are manifested by its drawings and calculation notes, reports etc. But if you take engineering design as a design for a project, it will have a broader meaning. Because, installation, commissioning, and operation all required some designs. In this respect, all these designs are manifested by our final product, the plant which we deliver to the owner.”

“ So for a system design, I think its results shall be amenable to scientific verifications, and they shall also be in compliance to laws and regulations. But it should also have some human concerns. For instance ergonomics, that is to say the designed object should be easier for human operation.”

Interviewer: “I would like to interrupt you at this point, because I feel that this type of ergonomics designs is in fact guided by a principle to avoid human errors. What do you think of this tendency?”

Mr. F: “It has both its pros and cons. Machines are not always reliable. Operation requires human inspections. In this respect, automation reduced human input in the operation of the system but it increases human inspections of its process. Automation makes the nuclear power plant safer but it doesn’t mean that our human inputs are reduced. On the contrary such inputs may be increased instead. Digital control machines replaced human operators; they might raise the nuclear power plant’s safety to a higher level. Such replacement is accompanied by a higher equipment cost. So from a cost and benefit perspective, it is not a straightforward gain without any lose.”

“ As a short summary of my perceptions of a good engineering design, it shall meet a series of requirements. Specifically the requirements set up by the owner, by the regulations and laws and our own procedures, the requirements of the future operators, the requirement of constructors etc. In all, the design should be easily understood, and be able to be adopted.”

Interviewer: “What are the shortcomings of our designs from your perspective?”

Mr. F: “What we are lacking in our design from my personal perspectives is that we have not established a set of matured design methodology. I think our engineers are capable and we have not seen any apparent flaws in our company’s policy.”

Interviewer: “Are you suggesting that we have never done a real completed engineering design for a nuclear power plant by ourselves?”

Mr. F: “Almost. I am questioning our approach of design. Because I feel that we are always performing a duplication of others’ design with our limited modifications. The EPR and the AP1000 are not our products. Our real products are those modifications. In this respect, the HL 1000 may be considered as our product but certainly CPR1000 is not that kind of a product. At least in the development of the HL1000, we go through its R&D, not just duplications or modifications. We start from the origin. If engineering design is defined to be duplications and modifications, I tend to think that our designs are workable in a realistic sense taking into the consideration of scheduling. But I still think engineering design should be something more creative. The HL1000’s R&D may be an example for that kind of engineering design.”

Interviewer: “How can we improve our design? What is the driving force of making improvements to our design?”

Mr. F: “I think this is an easy question. What is the driving force of our entire company? Profits. I have never questioned our engineers’ capability of doing a good job compared with those who I know in AREVA or in EDF. But what we are lacking is an experience, an experience that starts from the beginning of a complete engineering design. Our design is fragmented therefore we need more time to accumulate. Certainly our company should provide more opportunities for engineers to learn by working with in a real project. But the most important thing is that the company should provide some direct stimulates such as financial awards to our engineers to encourage their participation. Or company could consider such stimulates in terms of honor.”

I think the managerial aspect is also very important. We need to reduce the waste of our energy in the interfaces. We need to reduce disputes over trifles among our departments and engineering disciplines. To do this a more scientific approach of management should be relied on. I hope under a better management scheme, engineers can focus, or spend more time, on real design activities or learning, rather than wasting their time on handling trivial things which are in fact not engineering design. However, I think improving our management can only serve a supportive role. The most important thing is that engineers spend more time on real engineering design. As such the result will be different.

Good management may stimulate creative thinking among our engineers. Just now I am trying to say that even though hard working is important, but it doesn't mean that creative thinking can be naturally generated through hard working. Creative thinking is important for a better design.

Interviewer: "What do you think of our own small project? Will it bring some changes to our engineering design?"

Mr. F: "I think it has some modest pushing effects on changing our designs. Our small knowledge management project has clarified and probably visualized our design engineers' knowledge reserves. It made a connection of knowledge to their hands-on jobs. So, I think it will facilitate our engineers to get a better understanding of their work. But I would say that our project has its limitations, because it gives me a feeling that it is too narrowed, which can only be adapted to the existing knowledge management system. I mean too simplified. I always feel that we have missed a lot of things in the final report that we have submitted to the top-management.

By the end of interview, I had some discussions with Mr. F about our small project, which lasted for about 3 minutes. Both of us tended to think that the process of the project was in fact an attempt of performing a cross-disciplinary communication among CNPDC's and CNPEC's divisions and branches. In our research process we found that engineers in CNPDC's divisions were not quite aware of what other engineers think and what others know. Communication through the interfaces is simplified to information exchange. In this respect, we think our small project has fostered some cross-disciplinary communication. Now, at least, some of them have got a rough picture of what others think and know.

But we left a question unsolved after our discussion. The question is "what were our own motives of performing this small project? Did we do it for fame or money?"

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