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Entering the Nuclear Power Plant Supply Chain: The Japanese Case Study

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Abstract

The so called "nuclear renaissance" is creating a huge market for new nuclear reactors. One of the major criticalities in this field is the supply chain: few firms have the capabilities to work in this complex and highly demanding market, whereas many other are investigating the option to enter. The international scientific literature provides information regarding the high-level governmental aspects of nuclear power programs in different countries, but the analysis at firm and project level are almost inexistent. Moreover, the usual business models for the manufacturing industry are not suitable, since the nuclear market is very peculiar. In particular it is unclear how an EPC (Engineering, Procurement and Construction) company can enter in the project delivery chain. In order to answer this research question this paper investigates the Japanese case study. First it introduces the background of Japanese projects and after it focuses on three major companies that played the most relevant roles in delivering the Japanese reactors: Toshiba, Hitachi and Mitsubishi. The investigation of these case studies provides useful insights for firms willing to participate in projects related to the construction of nuclear power plants.

*Keywords:*Nuclear project, Case study Analysis, Project Delivery Chain, Engineering, Procurement and Construction

1 Introduction

The Nuclear Power Plants (NPPs) market is dynamic and growing. Even after the Fukushima Daichi accident (causing different reactions in governmental plans for nuclear energy development), several countries declared their renewed support and conviction in nuclear energy. Sweden, France, Finland, Hungary, Romania, Slovakia, Slovenia, Spain and other countries proclaimed intentions not to change nuclear policies (Foratom, 2011). One of the most clear acts of trust in nuclear power technology has been made by Saudi Arabia, with its intention to build 16 new nuclear reactors over the next 20 years, for a $300 billion estimated cost (ArabNews, 2011).

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Even if nuclear business is very significant, the scientific literature focuses mainly on technical topics like neutronics or thermal-hydraulic issues. Beside these, the scientific literature related to managerial topics often discusses the high-level, governmental issues concerning national nuclear power development. As showed in the literature review section there are very few papers dealing with the main contractors and EPC in the construction of nuclear plants. It's completely undefined, in particular, how an EPC, working in other businesses, can enter the nuclear market. For this reason, after the preliminary literature review offering no information on the topic of entering the nuclear Project Delivery Chain (PDC), the Case Study Methodology (with an exploratory approach) has been applied, at a country level, to Japan. The Japan choice seemed really appropriated since the high number of nuclear reactors built, the share of nuclear energy in Japan's energy portfolio and the number of Japanese firms being main players in this business.

2 Literature review

This section analyzes the most relevant existing scientific papers and reports published regarding the NPP Supply Chain around the world.

2.1 Literature focused on local markets

(Sung & Hong, 1999) describes nuclear power evolution in Korea, focusing on the role of the government, the technology transfer, the localization of NPPs and the main players. (Ahn & Han, 1998), included in (IAEA, 2000), describes the Korean strategy to obtain self-reliance in NPP technology. It provides details about different plant issues, such as the Nuclear Steam Supply System (NSSS) design, Turbo-Generator (TG) manufacturing and the Korean technology exporting experience. (Park C., 1992) focuses the attention on the Korean nuclear power program focusing on its success in achieving low costs and good operating performances. It provides an analysis on the major determinants to nuclear power development along with future prospects. (Valentine & Sovacool, 2010) develops two case studies over Japanese and South Korean nuclear power development, analyzing six factors (1) strong state involvement in guiding economic development; (2) centralization of national energy policymaking and planning; (3) campaigns to link technological progress with national revitalization; (4) influence of technocratic ideology on policy decisions; (5) subordination of challenges to political authority, and (6) low levels of civic activism) having a clear influence in supporting nuclear power development. (Lesbirel, 1990) describes, through the analysis of a Japanese NPP case study, a top-down and a bottom-up approach to understand perspectives of nuclear power actors in the Japanese context. (Mycle Schneider Consulting, 2009) provides information about the French nuclear power program, from strategies for the technology transfer, to the important role assumed by Areva and EDF as a worldwide player in nuclear market. (Collingridge, D., 1984) presents the nuclear development in the USA and UK, highlighting problems connected with the expected NPP performance, and issues about serial NPP orders versus piecemeal NPP orders. (Roche, 2011) describes the EDF large nuclear program with its PWR series of standardized reactors. He stresses the experience on the Architect/Engineer (A/E) role of EDF to launch the construction of a first EPR in Flamanville. (David & Rothwell, 1994) compares the amount of standardization in the U.S. nuclear industry versus the French one. The article proposes methods to measure the standardization amount in nuclear industry. (Plantè, 1998), included in (IAEA, 2000), summarizes the French experience in nuclear energy, and its success reasons, like standardization. Notable are the observations referring to financial synergies between the French Government and EDF.

2.2 General Reports

(IAEA, 2000) collects various papers regarding nuclear development in different countries. There are no relevant references to nuclear market itself: instead, economic and technological transfer issues are discussed. (IAEA, 2007) addresses the project management issues connected to NPP projects. (MPR, 2005) assesses the adequacy of infrastructures to support the deployment of NPPs in the USA. (MPR,

2010) assesses World's existing capability to provide large steel forgings, used to fabricate nuclear critical components (such as reactor vessels and steam generators), moreover discussing the possibility of establishing a forging facility in the U.S. to produce such components.

2.3 Literature review: results and gap

The main results of this introductive bibliographic analysis can be obtained through the cross analysis of the cited papers, cause even if some argumentations are not explicated they emerge as common elements of the papers, in particular:

- The government deeply influences the development of a national nuclear industry;
- Countries followed different paths to successfully deploy nuclear technology in their own State. The technology transfer is an interesting scientific topic, discussed in several papers.
- Capabilities required to companies working in NPP projects are heavily related to the contractual roles.

The main gap in the literature is the absence of references regarding how to enter the NPP business; describing paths, capabilities, time required and efforts. This paper aims to fill this gap through the Japanese case study analysis.

3 Methodology

The case study method applied in this research project is largely based on (Yin, 2003) and (Flyvbjerg, 2006). According to these scholars the potential of this research method in the field of human affairs, combined with the possibility to rely on multiple sources of evidence, are the main reasons for this methodological choice. Traditional prejudices over this research method are answered by the considerations of (Flyvbjerg, 2006) himself. In fact this approach, combined with the open narrative along the case development, results in a simple integration of the information without guiding readers opinion. Quantitative estimates about the enabling factors for an EPC company, showed in the next paragraphs, were deducted triangulating the information given by technical reports and data provided by the companies through published interviews, or websites. The best way to investigate this topic is to cluster the firms analyzed in homogenous cluster The following definitions of cluster of firms are based on (IAEA, 1999). According to this report, there are three different types of contractual approaches applied in NPP projects, namely:

- Turnkey approach, with a single contractor or a consortium;
- Split-package approach, where the overall responsibility is divided between a relatively small numbers of contractors, each of them taking charge of a large section of the works;
- Multi-contract approach, where the owner, or his A/E (Architect/Engineer), assumes overall responsibility for engineering the station, issuing a large number of contracts.

The multi-contract approach will be the reference for this paper, since this approach allows the subdivision of roles and scopes of work for a NPP project. Prime contractors are defined as the EPC companies awarded with a contract for any of the roles defined as follows (IAEA, 2004):

- A/E: Project management and engineering management support; owner's personnel training; support services to owner on procurement, construction & commissioning; other related activities;
- NSSS (Nuclear Steam Supply System) supplier: System & component design; equipment supply; provision of raw material specimens for Leak Before Break (LBB) analysis and other services (technical support, licensing and training);
- TG (Turbo-Generator) supplier: Equipment supply including design, engineering & related information; tests; services; training of owner's personnel; and spare parts;
- Construction contractors: Civil/architectural work, piping and cabling work, installation and erection of mechanical and electrical equipment, yard facilities, and commission support within their scope of work.

4 Case study on Japanese EPC industries

4.1 Introduction

The World Nuclear Association (WNA, 2011) provides much information regarding the background of Japanese energy policies. Before the Fukushima accident, nuclear energy accounted for almost 30% of the country's total electricity production (29% in 2009), from 47.5 GWe of capacity (net) to March 2011, and 44.6 GWe (net) from then. Before the Fukushima accident there where 50 reactors for the commercial production of electricity. Those reactors was built between 1974 and 2009 at a steady rate of about 2-3 units/year Japan started its nuclear research program in 1954, with Y230 million budgeted.The Atomic Energy Basic Law, which strictly limits the use of nuclear technology to peaceful purposes, was introduced in 1955. The law aims to ensure that three principles - democratic methods, independent management, and transparency – have to be the basis of nuclear research activities. Inauguration of the Atomic Energy Commission in 1956 promoted nuclear power development and utilization. Several other nuclear energy-related organizations were also established in 1956 under this law: the *Science & Technology Agency*; the *Japan Atomic Energy Research Institute* (*JAERI*) and the *Atomic Fuel Corporation* (renamed *PNC* in 1967). The first reactor to produce electricity in Japan was a prototype boiling water reactor: the *Japan Power Demonstration Reactor* (*JPDR*) which ran from 1963 to 1976 and provided a large amount of information for later commercial reactors. It also later provided the test bed for reactor decommissioning. Table 1 summarises the main elements of the Japanese nuclear program.

Table 1.LWR Improvement and Standardization Program (Nakasugi, 2009)

Major Purposes	*First Phase* 1975-1977	*Second Phase* 1978-1980	*Third Phase* 1981-1985
Improvement of Reliability and Capacity Factor (CP)	CP: about 70% Adopt SCC-resistant materials Improvement of SG, etc.	CP: about 75% Improved CRDM Improved fuel, etc.	Development and standardization: ABWR by reactor internal pump, fine motion CRD, and high performance fuel, etc.
Shortening Annual Inspection (AI)	AI: about 85 days Larger Containment Vessel Improved refuelling machines, etc.	AI: about 70 days Adoption of auto-exchanger of CRDM Improved fuel inspection systems, etc.	APWR by larger reactor core, water displacer rod, high performance fuel, etc. Improvement of conventional LWRs: AI (mainly turbine systems), radioactive waste treatment facility, construction methods, etc.
Reduced Occupational Exposure	About 75% of conventional plants Prevention of crud generation and crud removal Automated SG tube inspection, etc.	About 50% of conventional plants Wider application of automated machines to ISI Automated water quality analyser, etc.	Standardization program in aseismic design, licensing procedures, RW treatment, finalization of basic specifications of standard plants

Remembering that the goal of the paper is to present how an EPC (Engineering, Procurement and Construction) company or main contractor can enter in the project delivery chain the analysis shift now from a national level to a firm level. The firm will be analyzed according to the role presented in section 3. The information gathered, integrated with the literature review in section 2 will provide the ground for the consideration in section 6.

4.2 A/E, NSSS Supplier, TG Supplier: Hitachi

According to (Hitachi-GE, 2010), Hitachi started nuclear business in 1950s. A cooperation with General Electric (GE) was carried along during the 1960s. The major milestones of Hitachi NPP plants are: the first fully domestically produced NPP (1974); the first ABWR in the world (Hitachi/GE/Toshiba) (1996); the first ABWR with full scope (NSSS and BOP) (2006)

Hitachi – Road-To-Nuke

1. Achievement of the BWR core technology during the Japanese Nuclear Power Program from GE (Tsuruga-1, Tokai-2) and through Babcock-Hitachi's joint venture.
2. Establishment of a joint venture with Hitachi-GE Nuclear Energy: Hitachi-GE was oriented on the domestic ABWR market, while GE-Hitachi was committed to the U.S. market
3. Establishment of a consortium with Bechtel, in order to enter Chinese market, and achieve several minor participations abroad.

4.3 A/E, NSSS Supplier, TG Supplier: Mitsubishi Heavy Industries

Since its founding in 1884, Mitsubishi Heavy Industries (MHI) has been focused on manufacturing and development of the Japanese manufacturing industry. Major products and operations include engineering, manufacture and sale of ships, environmental improvement equipment, industrial machinery, aircraft, space systems, air-conditioner, etc. (MHI, 2011). MHI market includes aerospace, power-generation facilities, ships, industrial equipment, and home air conditioners (MHI, 2011). Mitsubishi is a NPP and steam generator supplier, providing planning, design, manufacturing, construction and plant maintenance (MNES, 2007). Since the 1950s, when Mitsubishi group first began to research and develop nuclear power generation, it took part in the design and construction of more than twenty NPP in Japan. Mitsubishi supply also products and services in the area of PWR power plants, including basic plans, design, manufacturing, construction and maintenance (MNES, 2007).

4.3.1 Recent Developments

On July 10, 2007 AREVA and MHI signed a Memorandum of Understanding, setting the framework of the joint venture to develop and market their new mid-sized nuclear reactor worldwide. The joint venture would develop an "advanced Generation-III" nuclear power reactor, the Atmea 1 (WNN, 2007). On September 28, 2007 MHI announced the signing of a contract to supply two steam turbine generators for the Westinghouse AP1000 Sanmen NPPs to be built in China. The order marks the company's first major project in the Chinese market for new nuclear constructions. The order is worth a reported 60 billion yen ($520.8 million). On January 31, 2008 MHI announced that steam turbines and generators for all four of China's AP1000 reactors are to be their own products (WNN, 2008).

Mitsubishi – Road-To-Nuke

1. As one of the largest Japanese manufacturing companies, MHI played a relevant role in developing Japanese Nuclear Power Program, promoting the PWR core technology both through its own R&D function, and through co-operation with Westinghouse;
2. MHI then experienced itself in the A/E role during several NPP projects;
3. MHI is now expanding its market: the agreements with Russia and China, the ATMEA joint venture with AREVA are both facts supporting this affirmation.

4.4 A/E, NSSS supplier, TG supplier: Toshiba Corporation

Toshiba is a manufacturer of advanced electronic and electrical products, information and communications equipment and systems, Internet-based solutions and services, electronic components and materials, power systems, industrial and social infrastructure systems, and household appliances (Toshiba, 2011). Toshiba Corporation employs almost 200,000 people and the total assets of the company are worth US$ 58,615 million. Toshiba's Power Systems Company delivers nuclear, thermal and hydroelectric power plants and develops new energy technologies; Toshiba, owning Westinghouse Electric, have with capabilities in both BWR and PWR.

Toshiba – Road-To-Nuke

1. Toshiba obtained the BWR core-technology know-how through the partnership with GE, during the first NPP projects in the Japanese Nuclear Power Program timeframe (Fukushima I-1&2&6).
2. The acquisition of the American nuclear firm Westinghouse enabled Toshiba to obtain PWR technology know-how, expanding its nuclear business influence worldwide, in particular aiming the USA and the UK.

4.5 NSSS Supplier: Ishikawajima-Harima Heavy Industries Co. (IHI)

IHI is a leading company in providing components for NPP since 1955. It provides Reactor Pressure Vessel (RPV), primary containment vessels, and piping system. IHI delivered and installed 24 RPVs for both BWR and ABWR, for domestic and overseas projects. IHI is the first N-stamp certificate holder of American Society of Mechanical Engineers (ASME) in Japan (JAIF, 2011). IHI is also involved in the development and construction of systems related to nuclear recycling. With regard to NPP equipment, IHI supplies conventional BWRs, ABWRs and PWRs. (JAIF, 2011).

IHI recently signed a Memorandum of Understanding with Toshiba, on the formation of a joint venture to manufacture steam turbine components for NPPs at home and abroad. The new company will be based at Yokohama and will manufacture casings and nozzles for steam turbines at new NPPs for PWRs and BWRs, for domestic and overseas markets, as well as providing maintenance services for installed equipment. IHI and Toshiba have a history of working together in building BWRs, for which IHI manufacturers RPV. The two companies show interests in PWR construction, through the presence of Westinghouse after Toshiba's acquisition.

IHI – Road-To-Nuke

1. IHI achieved the BWR technology know-how through the co-operation with GE, during the first Japanese BWRs projects;
2. IHI continued its BWR components development along with Toshiba, through a partnership, until the beginning of ABWR technology development (Hamaoka-5);
3. Continuous investment in achieving core authorization: Authorization for the manufacture of boilers & Class 1 pressure vessel, Authorization to use U, U2, S, N, NA & NPT Stamps of the ASME Level 1 of evaluation of welding shop performance, by Japan Power Engineering and Inspection Corporation (JAPEIC). Authorization for the manufacture of nuclear power, thermal power and chemical process equipment and devices in compliance with ISO 9001. Authorization for the Environmental Management System in compliance with ISO 14001

4.6 Constructor: Kajima Group

The Kajima Group is one of Japan's largest general contractors. Established in 1840 and headquartered in Tokyo, the Kajima Group has more than 15,000 employees serving customers in over 20 countries (Kajima, 2010). Kajima's businesses, according to (Kajima, 2010), are: Construction business, Real Estate Development business, Overseas Construction & Real Estate Development business. Construction business holds a 90.4% share in Kajima's global revenues (Kajima, 2010). The number of nuclear power plant units built by Kajima is 38, giving them a 62% share on total nuclear plants (not including the Rokkasho Reprocessing Plant). Relevant is its participation on construction since first BWR NPPs, while PWR NPPs construction participation started only in 1973 with Ikata-1 plant. A typical approach used by Kajima is presented in (IAEA, 2004). This report shows how Kajima took part as a civil work company, along with other Japanese company in the mastodontic Kashiwazaki-Kariwa's NPP project. The owner (TEPCO) assumed the overall management of the project for both units in a split package contract approach. The main design and construction work was carried out by a joint venture of manufacturers (Toshiba, Hitachi and General Electric). The civil work was done by a joint venture of civil construction companies (Kajima, Hazama, Shimizu, Takenaka and Maeda).

<u>*Kajima Group Road-To-Nuke*</u>

1924 Completes Japan's first concrete dam (Ohmine Dam) -

1949 Founds Kajima Technical Research Institute (first research facility in Japan's construction industry)

1950 First joint venture with Morrison-Knudsen of the USA

1957 Completes Japan's first nuclear reactor

1964 Establishes Kajima International Incorporated (KII) in Los Angeles, USA

Since '70s is a one of the main constructor in Japanese nuclear power plants.

4.7 Manufacturing: Japan Steel Works

Founded in 1907 in Muroran, Hokkaido, The Japan Steel Works, Ltd. (JSW) began as a joint venture with Britain's Sir W.G. Armstrong for the production domestic weapons in Japan (JSW, 2010). JSW's business ares are (JSW, 2010): Steel Production (50.4% of sales); Machinery Products (48.7% of sales); Regional Development (0.9% of sales). Steel Production business includes the production of steel in electric furnaces, manufacturing a broad range of cast products and steel ingots for forged products. The production capacity in ingots for forgings is 650 tons, while JSW's range of presses and hammers includes two 14,000-ton hydraulic presses. The forged products are mainly used in the electric power generation industry (fossil fuel, hydroelectric, nuclear), the steel-making, oil refinery and industrial machinery sectors. JSW also produces steel plates and steel structures composed by clad steel plates and clad steel pipes (JSW, 2010). JSW produces large forgings for RPV, steam generators and turbine shafts, and claims 80% of the world market for large forged components for nuclear plants. JSW supplied large forgings for nuclear industry and it is the only company worldwide with a 14,000 tonne hydraulic forgings press. JSW is planning some capabilities upgrade, connected with the criticality in large forgings supplies for NPP projects. JSW supplies the pressure vessels for Areva's EPR NPPs in Finland and France. Areva acquired 1.3% equity in JSW. JSW's capacity to 2007 was four RPVs and associated major components per year, but the company is tripling to twelve by 2012.

<u>*JSW– Road-To-Nuke*</u>

1907 Founded as a joint venture by three companies-Hokkaido Colliery Steamship Company of Japan, Armstrong Whitworth Co., Ltd., UK and Vickers Sons and Maxim, Ltd., US

1973-1974 Granted ASME U, ASME NPT and U2 Certificates. Start the manufacturing forgings for nuclear plant components to US Nuclear Regulatory Commission standards. Around 130 JSW reactor pressure vessels are in service around the world.

1994-1998 Granted ISO 9001, 9002, 14001 Certificates

JSW has a large budget for increasing its capacity. A JPY 50 billion ($523 million) expansion was completed in March 2010, and a second phase of JPY 30 billion ($314 million) will be complete in 2011. A second 14,000 tonne forging press was commissioned early in 2010 The company said that one of its main targets is to supply nuclear reactor pressure vessels to the Chinese and American markets, and it has advance orders from GE-Hitachi for ABWR and ESBWR components, as well as EPR pressure vessels.

5 Discussion

Japanese Nuclear Power Program focused on two major reactor designs: PWR and BWR. The reactors were and are delivered by the EPC firms presented in the previous sections, and summarised in Table 2

Table 2 – Main Japanese companies operating in nuclear market.

Company	*Techno*	*Roles*
GE	BWR	A/E,NSSS supplier, TG
Hitachi	BWR	A/E, NSSS supplier, TG
Toshiba	BWR	A/E, NSSS supplier, TG
IHI	BWR	NSSS supplier
Kajima	BWR/	Constructor
WH	PWR	NSSS supplier
MHI	PWR	A/E, NSSS supplier, TG
Japan Steel	PWR/	Manufacturing

The polarization of the three greater Japanese companies in the two different technologies created two BWR suppliers (Toshiba and Hitachi) and one PWR supplier (MHI), with foreign partners as GE and WH. It is possible to notice that Toshiba, Hitachi and MHI covered three roles in NPP projects: A/E, NSSS supplier and TG supplier. This peculiarity allowed Japanese companies to achieve relevant synergies in developing nuclear projects.

For what about MHI, Hitachi and Toshiba, it can be affirmed that Japanese firms became self-reliant after 2 to 3 NPP project participations. On a pure technological point of view, there have been no differences for firms between BWR and PWR technologies, except for TG suppliers. This is a marker, indicating that PWR's TG systems are not different from TG systems for conventional power plants, while BWR's TG systems are. Regarding the Constructor's role, no particular pattern emerges: even if two major competitors are present (Obayashi and Kajima), it is possible to observe a great competition among several companies since the first NPPs (both BWRs and PWRs). This can be connected to the lack of particular know-how requirements in the construction operations.

Moreover, the Case Study shows the use of partnerships as a strategic factor (Table 3):

- MHI established ATMEA, a joint venture with Areva in order to promote PWR technology all over the World;
- Toshiba acquired Westinghouse Electric Company to enter PWR market, and signed an agreement with IHI and Shaw to form a complete consortium in manufacturing (NSSS supplies) and construction fields too;
- Hitachi had a long-time agreement with GE to develop BWR technology and recently founded GE-Hitachi (dedicated to the US market) and Hitachi-GE (dedicated to Japanese market) in order to promote BWR technology all over the World. In addition, Hitachi acquired Babcock-Hitachi, joint venture established to develop NSSS supplies capabilities during the Japanese Nuclear Power Program.

Finally, even if JSW is not a proper prime contractor in NPP projects, the company has a fundamental role supplying large forgings. Because of low competition and high lead-time market, creating a privileged relationship was the main goal of both Hitachi and MHI in acquiring JSW's stakes.

6 Conclusions

The literature review and the Case Study show different possible ways to enter nuclear business:

- Strong investments in R&D during a national Nuclear Program development (as MHI, Hitachi, Toshiba) and agreements with foreign technology's experts (like GE and WH) for the first NPPs;
- Acquisition of a contemporary active player in NPP business (Toshiba acquiring Westinghouse in order to enter PWR market);
- Strategic stocks acquisitions (Hitachi with JSW; Toshiba with IHI; MHI with JSW) and partnerships with players already active in nuclear power business (Hitachi with GE; Toshiba with Shaw, IHI, WH; MHI with Areva).

Table 3 - Japanese nuclear industry: strategies and partnerships

Company	*Technology supplier partners*	*Strategies in nuclear business*	*Major companies acquired, mergers, etc.*	*Partners for joint ventures, alliances, …*
Toshiba	General Electric (BWR)	Company acquisitions, agreement, acquisition in stakes	Westinghouse (PWR), IHI (BWR)	Shaw
Hitachi	General Electric (BWR)	Mergers, acquisitions	Babcock-Hitachi	GE, JSW
MHI	Westinghouse (PWR)	Company acquisitions	MAPI	Areva, JSW

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