How EPC firms can enter the nuclear renaissance

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Research paper

THE SO CALLED "NUCLEAR RENAISSANCE" IS CREATING A MILLIONAIRE MARKET FOR NEW NUCLEAR REACTORS. Few firms have the capabilities to work in this complex and highly demanding market, whereas many other are investigating the option to enter. Quite surprising the international scientific literature provides information regarding the high-level governmental aspects of nuclear power programs in different countries while the analysis at firm level is almost inexistent. Moreover the usual business models for the manufacturing industry are not suitable since the nuclear market is very peculiar. In particular is unclear how an EPC (Engineering Procurement and Construction) company can enter in it. This paper deals with this question investigating how an EPC firms or general contractor can enter in the nuclear market. The case study methodology has been widely used to understand the time, cost, enabling factors and barriers to enter in the nuclear business in the most important roles: Architect/Engineering, NSSS supplier, TG supplier, Construction. The results show that there are strong similarities among companies acting as main contractor in the same field; therefore it is possible to generalize a large set of meaningful lessons learned.

Keywords
Economics, Supplier, EPC companies, Project delivery chain, Nuclear industry

INTRODUCTION AND RESEARCH QUESTIONS

Nowadays the nuclear market is in a really dynamic condition. Even after the Fukushima Daichi accident (which caused different reactions in governmental plans for nuclear energy development) several countries declared their renewed support and conviction in nuclear energy. Among the others United Kingdom, France, Romania, Slovakia and Slovenia declared their intentions to not change their nuclear policies (Foratom, 2011). One of the most positive demonstrations toward the 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) or the event more recent plans of Belarus and Turkey. Even if the market is very attractive the project delivery chain (supplier, general contractors, advisor etc.) is not enough developed to satisfy the markets demand; therefore many firms are expected to enter the nuclear business. The Project Delivery Chain (PDC) is defined as the individuals and organizations involved in the project, with interests that may be positively or negatively affected as a result of project execution. The components may also exert influence over the project and its results (Project Management Institute, 2000). The PDC for a Nuclear Power Plant (NPP) project changes along with the contractual approach used, however the following designations are always present (IAEA, 1988):

- Public authority;
- Regulatory body;
- Utility;
- Main contractor;
- Architect-engineer (AE);
- Consultant;
- Subcontractor.

This paper deals with EPC (Engineering Procurement and Construction) firms and therefore focuses on the roles of Main Contractors and Architect/Engineer (AE). Main contractors are the organizations in charge of the execution of complete functional system (packages) of the nuclear power project. They are key stakeholders in the project governance (Ruuska et al., 2011) and their decisions are fundamental for the project success as demonstrated by the recent projects "Olkiluoto 3" and "Flamanville 3" (Locatelli and Mancini, 2012). The scope of a main contract typically comprises a fairly self-sufficient package with a minimum of external interfaces, in the form of major sections of the plant, systems or services. The main contractors would plan, engineer and commission the contracted portion of the plant according to the specifications and requirements of the utility and with allowance for the interfaces to other contractors, often under a package contract with a fixed price and schedule. They are responsible for the management of the project and sometimes the whole program (Locatelli and Mancini, 2010). A main contractor independently manages the subcontracts for his portion of the plant, possibly with a consent right by the utility.

In the Nuclear Business there are mainly three different types of contract (IAEA, 1999):

- Turnkey approach, where a single contractor or a consortium of contractors takes the overall responsibility for the whole works.
- Split-package approach, where the overall responsibility is divided between a relatively small numbers of contractors, each coping with a large section of the works.
- Multi-contract approach, where the owner, or his architect-engineer, assumes overall responsibility for engineering the station, issuing a large number of contracts.

Due to its widespread application the multi-contract approach will be the reference for this work moreover, with the opportune adaptations (mainly it changes the owner and the risk sharing approach), also the other approaches can be traced back to this one. Multi-contract approach allows the subdivisions of a NPP project in a set of standard roles and scopes of work. In this type of approach, prime contractors are defined as the company (or the companies) winning a contract for any of the roles defined in Figure 1.

The multi-contract approach showed in Figure 1 divides roles as follows (IAEA, 2004):

- Architect/Engineer (AE): Project management and engineering management support; owner's personnel training; support services to owner on procurement, construction & commissioning; other related activities. The term AE is generally applied to organizations which specialize in planning, engineering and managing industrial installations and buildings. AE firms can therefore combine a great deal of experience and accumulate expert know-how transferable from one project to another.
- Nuclear Steam Supply System (NSSS) supplier: System & component design; equipment supply; delivery of raw material specimens for LBB (Leak Before Break) analysis and other services (technical support, licensing and training);
- Turbo-Generator (TG) 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.

The percentage of the total overnight cost allocated to each role is showed in Table 1.

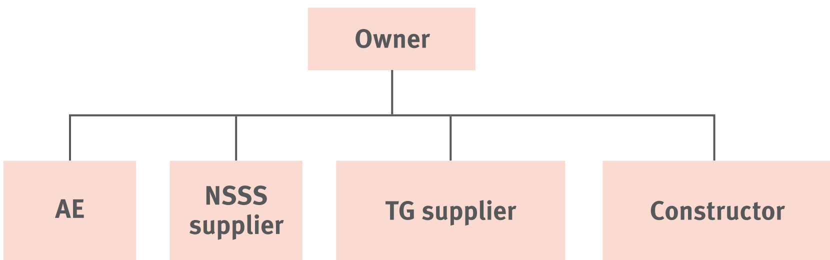

Figure 1 **NPP's PDC: multi-contract approach**

Reference plant	Country	Technology	Capacity (MWe)	NSSS supplier (%)	TG supplier (%)	Constructor (%)	AE (%)
1 (*)	France	PWR	1450	29.0	26.0	17.0	-
2	USA	ALWR	900	17.7	20.5	16.5	9.0
3	USA	ALWR	1300	18.6	21.6	17.2	9.2
4	Germany	PWR	1380	32.0	28.7	20.9	13.8
5 (**)	Korea	PWR	1000	31.0	11.0	17.0	36.0

Table 1 **Shares of NPP's overnight costs, mainly from (NEA, 2000).**
(*)Data based on an average cost calculated for a series of 10 units, which includes a part of the first-of-a-kind costs.
(**) Based on Korean plants 10-11, referring to (Sung and Hong, 1999). AE's high share is due to the Technology Transfer costs.

So, even if the market is huge and really attractive is unclear how an Engineering Procurement and Construction (EPC) firm working in other sectors (chemical, Oil&Gas, etc.) can enter in the nuclear business. In particular the literature shows a huge lack of information concerning modalities and requirements for a General contractor/ EPC company to enter the nuclear business in these aforementioned roles, therefore this gap arises five main research questions:

Q1: Which are the drivers shaping the PDC in a nuclear power plant project?

Q2: Which are the main barriers to enter the nuclear power plant business?

Q3: Which are the enabling factors leading a company to proficiently enter the nuclear power plant business?

Q4: Do exist paths, leading to an entry in nuclear power plant PDC?

Q5: How much time and investment must a company face to enter nuclear power plant business? Are they different along with diverse contractual roles?

In order to answer to these research questions this paper summaries the information provided by several case studies of firms already entered the nuclear business.

Case Study methodology

Case Study methodology is a scientific method extensively used as a technique to describe and understand not only the players of global nuclear market, but also dynamics leading the companies to enter the market. In order to understand the different scenarios analyzed, it is necessary to present the theory of this research method and how it has been implemented.

Description

The case studies presented in this paper have been developed according to two main references: (Yin, 2003) and (Flyvbjerg, 2006). According to (Yin, 2003) archival analysis in case study research can be used to answer such questions as what, how often and when. Concerning the validity and reliability of this research, the use of this type of rich public evidence, archival records and documentation, has both advantages and disadvantages. Typically archival and documentary data are completed with other types of evidence such as interviews; hence our sources of evidence may potentially affect the validity of our findings. On the other hand the large potential of this Research Method[1] in this field, combined with the possibility to rely on multiple sources of evidences, are the main reasons for this methodological choice. This approach results in a simple integration of the information without guiding readers' opinion. Another advantage of the use of this kind of public data is the fact that we can openly discuss the data and our findings in the analysis, by posing the data and the findings for public critique. Such public critique may help to test the correctness of the content of our analysis. The purpose is leading the reader to the outcomes of this work, supported by evidences listed.

Implementation

The implementation of our case studies follows the "top down approach" presented in Figure 2. The purpose is to understand high-level decisions (typically governmental), and consequently analyze industry's response. Final focus is given to single companies, with details about their path to enter the nuclear business.

With this approach our results and conclusions are useful at two different levels i.e.:

Governmental/policy maker level: since the goal of a policy maker is to maximize the present and future welfare of its citizens, it needs to understand the macro aspects and drivers of a certain business. In order to maximize the outputs from its scarce resources (money, intellectual assets etc…) it needs to assign these resources where they are most effective, so it is necessary to understand which type of firm deserves the greater support and how to provide it.

1 Traditional prejudices over this Research Method are answered by the considerations of (Flyvbjerg, 2006).

2 These four countries include the two largest Nuclear Consortia: the Areva-MHI, and Toshiba-Westinghouse.

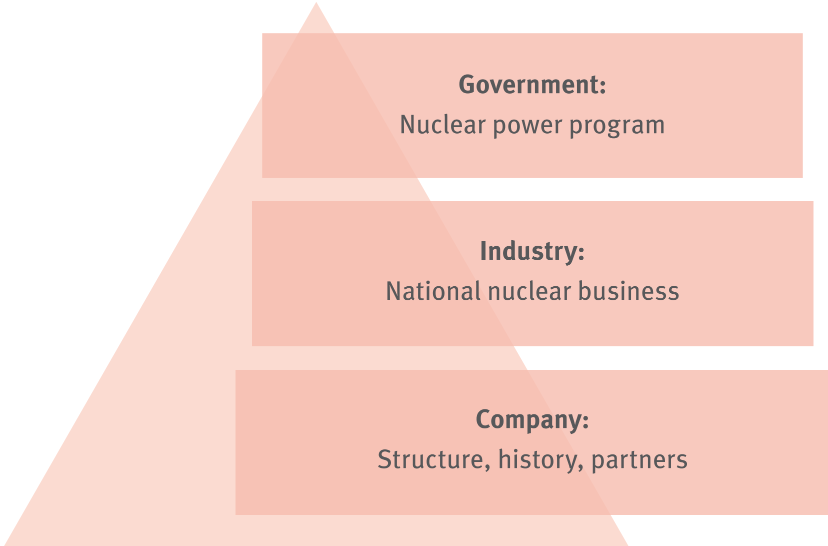

Figure 2 **Top down approach for Case Studies:**

Firm level: a certain firm, considering its capabilities, assets and core business aims to understand if it would be profitable or not to enter in the nuclear business, and in case of, which benefits would be expected and which gaps have to be overcome.

The parameters used for the country selection were the followings:

- Development of a national nuclear power program
- National companies being part of nuclear consortia
- Presence of a national nuclear industry
- Availability of scientific articles, regarding the country's nuclear policies
- Political situation

These parameters led to the choice of four main countries to analyze: Japan, USA, Republic of Korea, and France[2]. These are the first countries in terms of nuclear reactors built inside the country, excluding Russian Federation. According to (Yin, 2003), a Pilot Case Study was prepared before developing the case studies. The United Arab Emirates' (UAE) first NPP project, with the contract's bid won by the Korean Consortium led by KEPCO, has been the topic of this Pilot (see Appendix: Pilot Case Study: UAE's bid for a new NPP project); Figure 3 shows countries and companies analyzed. For the purpose, sources of evidence are integrated through the analysis of three different bibliographic reviews.

The sample considered in this paper includes 21 companies involved in different NPP projects' roles (Figure 3). The countries were these firms are based host a total of 237 NPPs (54% of World's total). The bibliography analyzed (Table 2) comprises scientific papers (organized in three different clusters – Korea & Japan, France & USA, UAE contract bid), technical reports (IAEA, NEA, MPR etc.) and archival records (JAIF, 2003) (Scientech, 2010) (Industcards, 2011 a). Along with this documentation, every company was studied through websites, annual reports, news, archival records and conferences reports.

The PDCs are defined elaborating and triangulating information from both archival records (JAIF, Scientech, Industcards) and other sources (company website, annual reports, news, technical reports).

	Korea	Japan	USA	France
Scientific Literature	(Sung and Hong, 1999) (Choi et al., 2009) (Ahn and Han, 1998) (Park, 1992) (Valentine and Sovacool, 2010) (Lesbirel, 1990) (Pickett, 2002) (Park and Chevalier, 2010) (Berthelémy and Lévêque, 2011)		(Leny Pellissier-Tanon, 1984) (Collingridge, D., 1984 a) (Collingridge, D., 1984) (Golay, Saragossi and Willefert, 1977) (Grubler, 2010) (Roche, 2011) (Boulin and Boiteux, 2000) (David and Rothwell, 1994) (Plantè, 1998) (Davis, 2011)	
Technical Reports	NEA, 2000) (IAEA, 2007) (MPR, 2005) (MPR, 2004) (MPR, 2010) (IAEA, 2000)			
NSSS design and manufacturing	KEPCO E&C	Hitachi, MHI, Toshiba	Westinghouse, General Electric	Areva
TG supply	Doosan Heavy Industries	Hitachi, MHI, Toshiba	Westinghouse, General Electric	Alstom
Construction	Daelim Industrial, Samsung C&T, Hyundai E&C, Daewoo E&C, Doosan E&C	Kajima	Bechtel, The Shaw Group	Vinci, Bouygues
AE	KEPCO E&C	Hitachi, MHI, Toshiba	Bechtel, The Shaw Group	EDF

Table 2 **The sample: every company has been analyzed through websites, annual reports, news and archival records.**

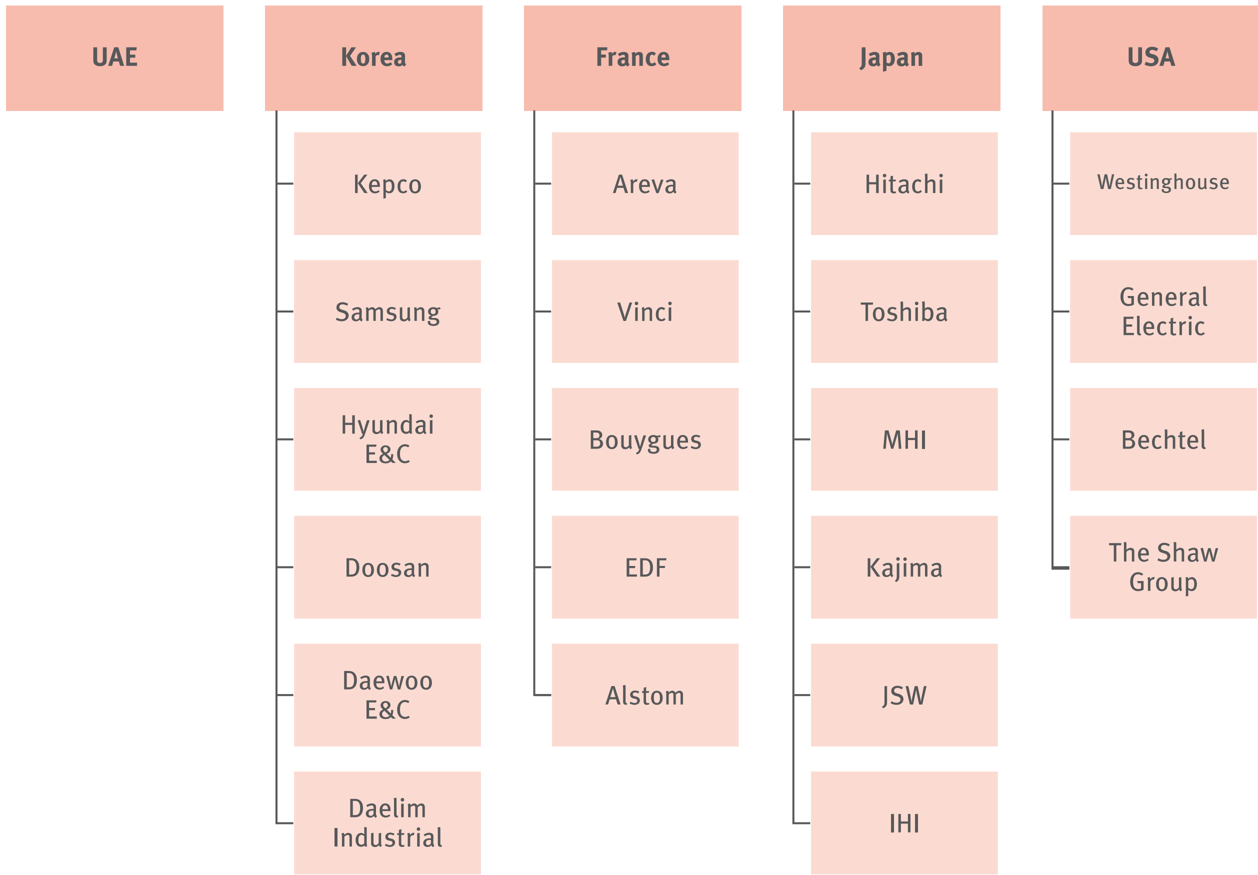

Figure 3 **Multiple-Case Study approach chosen: countries and companies analyzed.**

The first step involves the subdivision of NPPs, according to the different technologies (PWR and BWR). Then, NPPs are chronologically ordered respect to the date of order of the plant itself (or the construction start, according the available information); these tables have been the basis to develop the cases. Governmental issues (connected with agreements, policies, and laws promoting nuclear power development) were analyzed through scientific papers, which discussed about those topics diffusely. The national industry situation and companies' information were deducted from the other sources of evidence available (Annual Reports, Websites, News, and Technical Reports).

The study of governmental approaches to develop nuclear power programs provided information about the common strategies adopted in the countries interested in developing a national nuclear industry.

In particular the cases highlight the possible choices of:

- Having a series of turn-key contracts deployed by foreign suppliers (if domestic industries have not capabilities in the nuclear sector or the government is not interested in developing a national nuclear industry - i.e. UAE).
- Founding joint ventures between local and foreign companies, if local industries are supported by local government (i.e. France, with Framatome), with a Technology Transfer purpose.
- Co-operation agreements (i.e. Toshiba and General Electric, Mitsubishi Heavy Industries and Westinghouse) with local participation since first projects. This is the case of an already developed local industry.

In each Case Study, domestic self-reliance was achieved after several project participations. This fact, compared through the analysis of archival records, showed that construction's prime contractual role is to involve local companies since the first national projects i.e. to increase the so called "local content". Usually the TG supply's prime contracts are often controlled and detained by the NSSS suppliers. Technology Transfer processes highlighted the fact that some roles (such as AE and NSSS supplier) require a long time to develop knowledge by the Learning-by-doing process. Companies were then analyzed through the prime contractual role point of view. Main information obtained regarded:

- Companies' history.
- Acquisitions, mergers, partnerships.
- Technology Transfer through other companies.
- Nuclear business development.

The information was used to create a qualitative matrix, to highlight different paths followed by the companies, and focus on similarities between choices. Figure 4 shows an example of matrix for the Shaw Group: it presents the "nuclear path", with motivations deducted by evi-

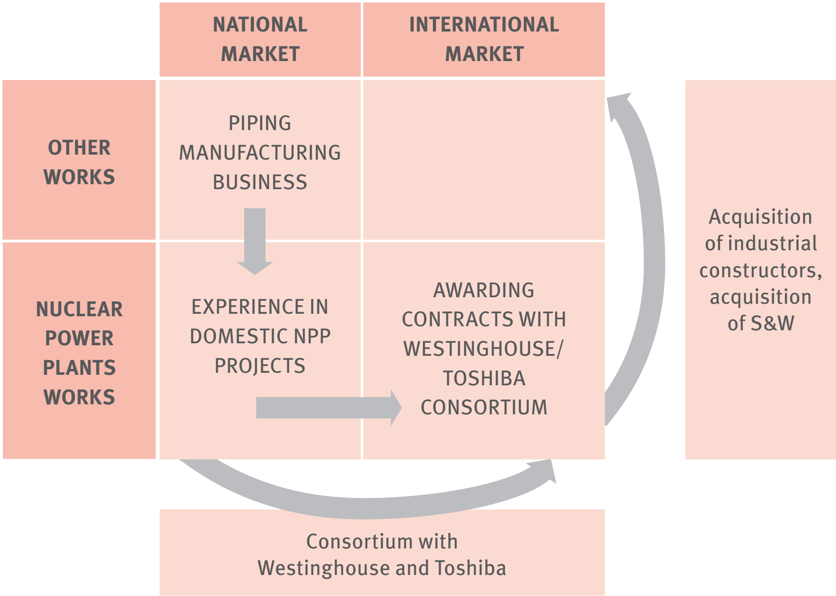

Figure 4 **The Shaw Group: nuclear "path"**

dences, causing the transitions between quadrants. All the information collected contributed to define these shifts. The matrix model is used for all the companies analyzed. Shifting is represented by an arrow and is tested by the analysis over the company's history. In the side boxes are drawn reasons, events and strategies leading to the shifting. Figure 5 shows the prospect of the sources and the integration process guiding to the Research Answers.

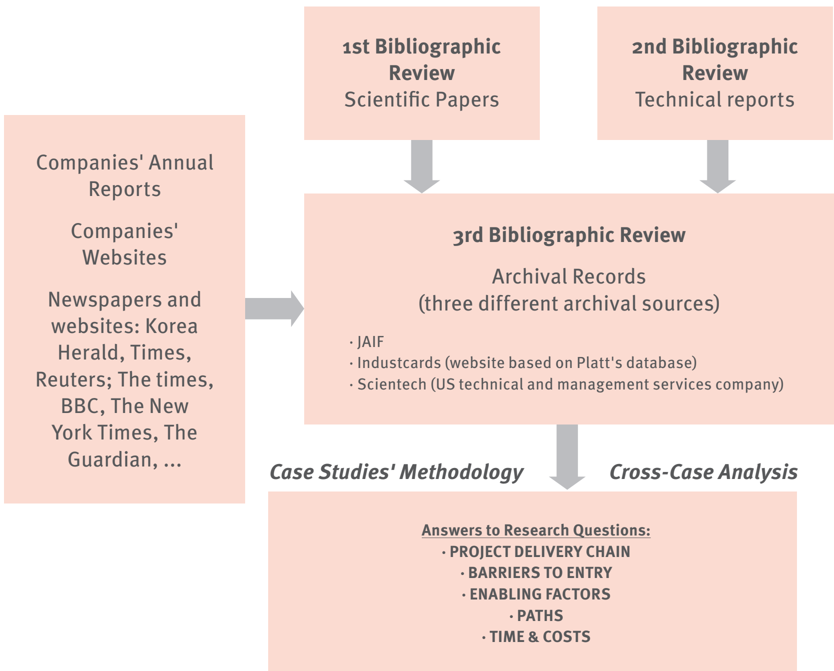

Figure 5 **Methodology and sources of evidence for the work: three different bibliographic sources have been reviewed, along with the application of Case Studies' Methodology**

Results

Barriers and enabling factors

Barriers to entry

The evaluation of the barrier to entry in nuclear market can be deducted from the integration of information contained in scientific papers and cross-case analysis of the case studies.

The most evident barriers to entry in the nuclear market is the government support. Government's support to national companies and the presence of a nuclear power program is a "Condicio sine qua non" to enter the field. Beside the government role, the case studies prove as there are not EPC companies directly entered the international nuclear market as a prime contractor. Each EPC (or major contractor) had past experiences in national NPP projects, before shifting to foreign NPP projects. In presence of a governmental support other barriers are role-dependent, according to the prime contractual role assumed by the company. They are presented in Table 3.

Historically, technological barriers (i.e. the NSSS design capabilities, or the AE ones) were bypassed with a government founding support (to self-develop the capabilities), or partnerships with foreign companies, through a Technology Transfer process. The specific role of NSSS manufacturer presents the large-forgings' supply chain problem. Companies such as Hitachi and Mitsubishi secured a share of Japan Steel Works' stakes, in order to have privileged relations, with one of the few world suppliers of these components. The investment in a manufacturing plant capable to forge such components, according to (MPR, 2010) is unprofitable unless it is fully exploited. As noticed, the construction's prime contract seems to be the most appealing for a national EPC company.

Enabling factors to enter the nuclear market

Enabling factors are the capabilities that a company needs in order to satisfy the requirement of a prime contractual role.

Role		Government support as first main barrier	"Other" barriers / Capabilities	Strategy to bypass "other" entry barriers
NSSS Supplier	Design	Yes	Core Technology	Technology Transfer
	Manufacturing	Yes	Large Forgings' Supply	Great investment or privileged relationship with supplier
AE		Yes	Basic and Detailed Design	Technology Transfer
TG Supplier		Yes	NSSS suppliers' "power"	Technology Transfer
Constructor		Yes	Dimension and capabilities	Technology Transfer

Table 3 **Barriers according to the prime contractual role covered by a company**

This can be summarized in three main categories:

- Workforce
- Qualifications
- Technological know-how

Partial information about the enabling factors' issue has been reported by (IAEA, 2007) (MPR, 2004) (MPR, 2005) (MPR, 2010). Several matches between data were found during the development of Case Studies (Energybiz, 2007) (Roche, 2011). The enabling factors are strictly connected with the technical role assumed in the project's context. A summary of the results is reported in Table 4.

One of the most important enabling factors to enter the nuclear business is the certification. American Society of Mechanical Engineers – ASME – is the

Technical role in the project		"Other" barriers / Capabilities	Basic design	Detailed design	Total
AE	Level of effort (man-hours)	-	300,000-500,000	2,500,000	3,000,000
	Staff	20-30 experienced engineers and technicians	200-300	Depending on NSSS, TG, BOP manufacturer design and site conditions	-
	Period (years)	Up to 2.5	0.5-1	3-5	3-5
	Cost	-	-	-	10% total NPP cost (not first of a kind)
Technical role in the project		**Components' design**	**Qualifications**	**Other enabling factors**	
NSSS and TG Manufacturing	Level of effort (MH)	20,000,000	ASME Certifications, depending on the particular component	Large forgings require sufficient manufacturing capabilities (for the Reactor Pressure Vessel)	
	Number of items	30,000			
Technical role in the project		**Preparation of site infrastructure**	**Erection of plant buildings and structures**	**Plant equipment, components and systems erection and installation**	**Other enabling factors**
Construction	Staff	50 to 150 craftsmen 10-20 professional managers	1,000 to 1,200 at the peak	1,300 people (technicians and craftsmen)	Advanced construction technologies and ASME Certifications

Table 4 **Enabling factors for NPP projects: subdivisions by contractual role. A synthetic description of capabilities required is shown, for any prime contractual role. (IAEA, 2007) (MPR, 2004) (MPR, 2005) (MPR, 2010)**

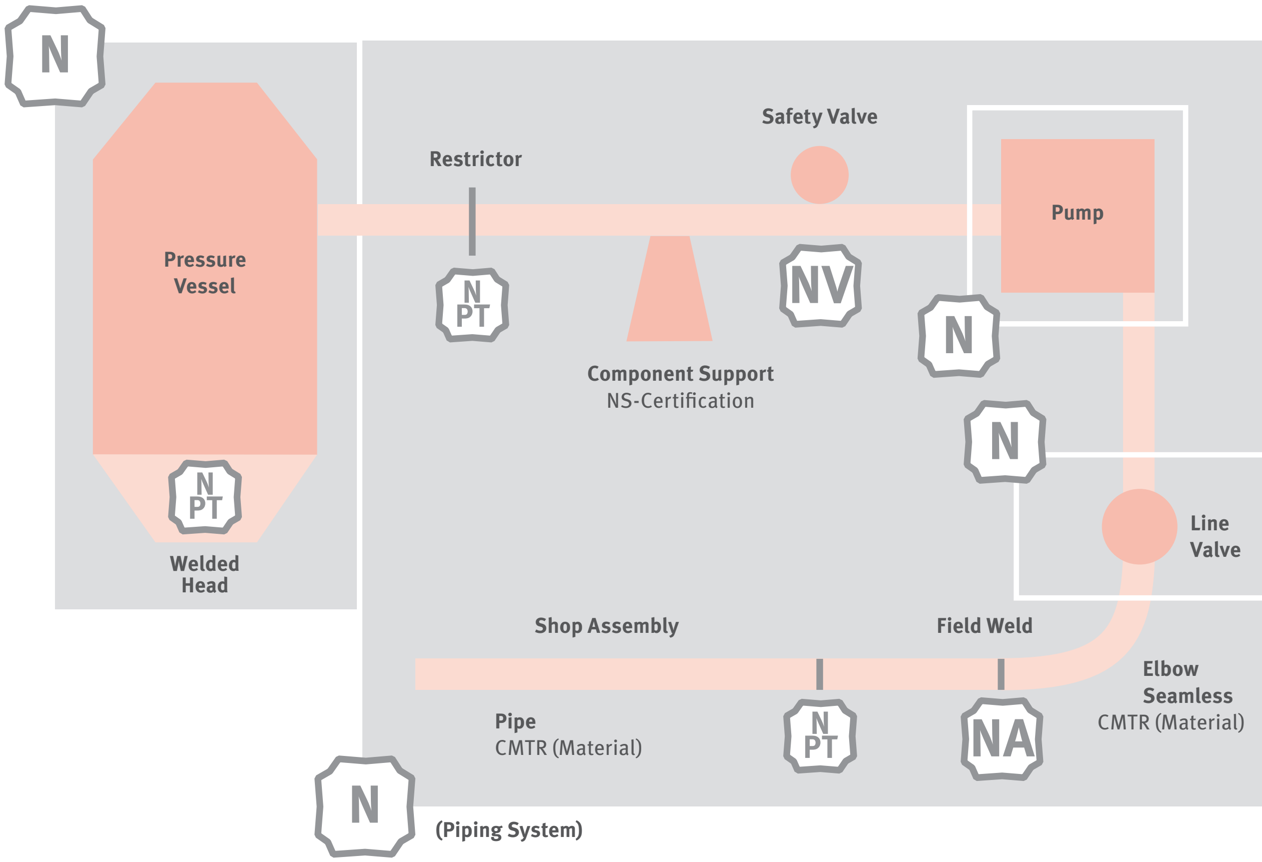

Figure 6 **Example of ASME's Stamps required, adapted from (ONE/TUV/BV, 2009).**

most recognized at a global level, however it is not the only one, e.g. French companies require the RCC-M Certifications (that are a development of ASME certification). ASME's NA (Nuclear Installation and Shop Assembly) and NPT (Nuclear Partials) stamps or equivalent are required to operate in the NPP's construction business. These stamps certificate the company's capabilities in terms of assembly of components and welded parts of nuclear components (ASME, 2011 a) (ASME, 2011 b). Figure 6 shows an extremely synthetic idea of Stamps required during a NPP projects: the scheme presents the main elements in a nuclear island requiring the ASME stamp certification. The synthetic scheme puts focus on the different stamps required. Parts of ASME Stamps are dedicated to the manufacturing process, but there are Stamps coping with the welding process, the assembly or the component supports. Qualifications involve nearly all the companies participating in a NPP project.

	NATIONAL MARKET	INTERNATIONAL MARKET
OTHER WORKS	HITACHI (BWR) TOSHIBA (BWR) MITSUBISHI (PWR) EDF (PWR) BECHTEL (PWR-BWR) SHAW (PWR-BWR)	BECHTEL (PWR-BWR)
NUCLEAR POWER PLANTS WORKS	KEPCO E&C (PWR)	KEPCO E&C (PWR) HITACHI (BWR) TOSHIBA (BWR) MITSUBISHI (PWR) EDF (PWR) BECHTEL (PWR-BWR) SHAW (PWR-BWR)

Figure 7 **Typical pattern for AE's prime contractors: almost all companies follow the "dotted" path: from national generic market to national nuclear market. Bechtel is the only company following the "continuous" pattern.**

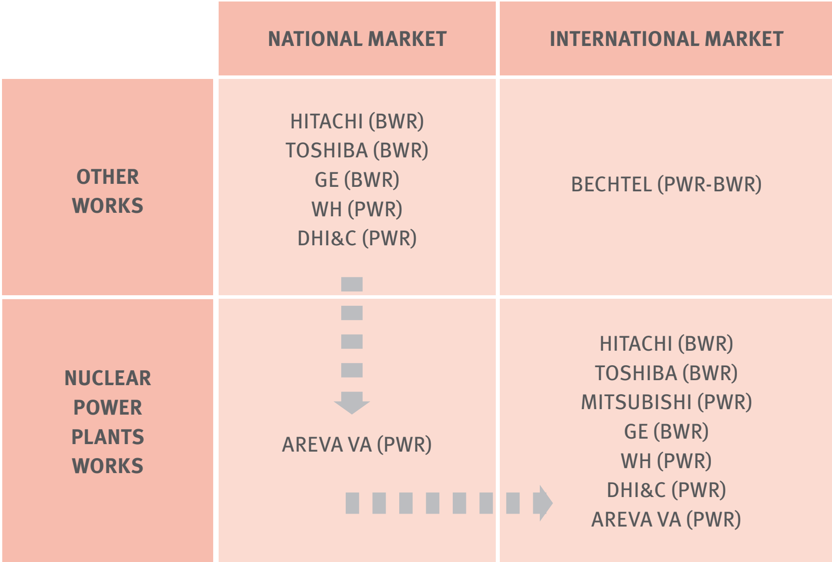

Figure 8 **Typical pattern for NSSS supply's prime contractors: companies follow the green path. Areva started directly in the national nuclear market: the company was born through a merger of companies already operating in nuclear market.**

(Voutsinos, 2009) reports information regarding ASME Qualifications in NPP projects.

Another critical factor is the Technological Know-How. Technological Know-How in the construction of new NPPs involves the management of advanced techniques focused on shortening the project's schedule. These techniques are mainly (Hitachi, 2008 a) (Hitachi-GE, 2010 b) (Hitachi-GE, 2010 a) (Toshiba America Nuclear Energy, 2010):

- Modularization;
- Open-Top Construction;
- Very-Heavy Lift cranes (VHL);
- Pipe bending machines;
- Automatic welding machines;
- Automatic rebar assembly machines (for ABWRs).

General paths leading to a nuclear market entry

The Case Study methodology, along with the matrix approach, shows similarities among companies. Similarities can be found between countries beginning a nuclear program through a Technology Transfer's process. A global picture of paths followed by the World's major players has been generated by applying the matrix described in par. 2.2 (i.e. Figure 4) and comparing different companies operating in same contractual roles. In the next sections Figure 7, Figure 8 and Figure 9 show the results of this analysis.

Architect/Engineering

Architect/Engineering companies deal with Technology Transfer processes. Large part of these companies shifted from national businesses to international NPP projects partnership with NPP built inside the country (Figure 7). A remarkable example is KEPCO E&C that has been founded to achieve core technology capabilities and started from the nuclear field (KEPCO E&C, 2011). The only exception, Bechtel (Bechtel, 2011), reflects the business' orientation of the company itself. Bechtel could be described as a construction-oriented company (more than AE). In facts Bechtel's path matches with results of the Construction business' matrix[3].

3 This fact is due to the impossibility to split roles for a company operating in both A/E's and Construction's fields.

NSSS supplier and TG supplier

Each company analyzed shifted from national market to national nuclear business then to international NPP projects (Figure 8).

This prime contractor's role presents Technology Transfer's issues, similarly to the AE role. The know-how was achieved through partnerships (with governmental support, i.e. (Barrè, 2008) (WNA, 2011 a)) and with synergic efforts in R&D since the first years after the WWII (i.e. (WNA, 2011 a), (WNA, 2011 b)). The only exception is Areva since it started its path into nuclear business directly. Its foundation was committed to develop nuclear technology with the merger of Framatome (now AREVA NP), Cogema (now AREVA NC) and Technicatome (now AREVA TA) in 2001 (AREVA, 2009). NSSS suppliers are also often TG suppliers for a NPP project. In France, where the government has a stronger decisional power than any other analyzed country (since its shareholdings in many national nuclear-related companies) Alstom is the privileged TG supplier (Alstom, 2011). This represents one of the few exceptions evidenced.

Constructor

The largest part of analyzed companies entered national nuclear business starting from international businesses (Figure 9). The exception is The Shaw Group. Before the acquisition of Stone & Webster (S&W, 2011) (The New York Times, 2000), its core business was mainly piping manufacturing (Shaw, 2011). The acquisition of an historic large-engineering company such as Stone & Webster led to a direct entry into NPP projects' business, with the "instantaneous" acquisition of the capabilities. The Shaw Group shifted directly from national conventional market to national nuclear business. The Stone & Webster's acquisition is the motivation for Shaw's "instantaneous" knowledge's acquisition. Stone & Webster was a large-engineering company already operating in nuclear business. Companies, after the

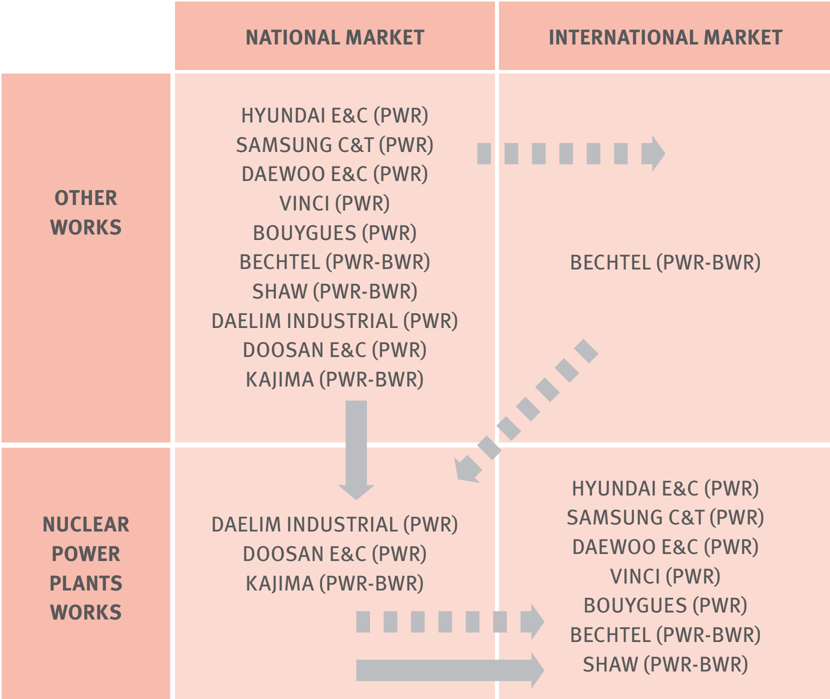

Figure 9 **Typical pattern followed by Constructors' prime contractors: almost all companies follow the "dotted" path. Only The Shaw Group shifted directly from national conventional market to national nuclear business. The Stone & Webster's acquisition is the motivation for Shaw's "instantaneous" acquisition of knowledge. S&W was a large-engineering company already operating in nuclear business.**

acquisition of an engineering-oriented company, followed a path more compatible with the AE's ones.

Learning process and time to enter the nuclear business

Time and costs required to enter the nuclear business depend mainly on the role covered into the PDC. Most of NPP projects in a country are built in parallel in order to benefit from early projects due to the learning curve process. So a year-based learning process estimate is not particularly indicative: for our purposes time estimation will be defined in terms of number of projects participations. This approach has been used for Japanese, Korean, French and US NPPs see from Table 5 to Table 9.

Architect/Engineering

Time-to-market strongly relies on Technology Transfer and learning-by-doing processes. This evidence is reflected in KEPCO E&C and other companies such as EDF or Japanese ones (MHI, Hitachi, Toshiba) (Barrè, 2008) (WNA, 2011 a)

	Plant	Type (MWe)	AE	NSSS Supplier	TG Supplier	Constructor	Construction period
Plant 1	Kori 1	PWR (587)	GILBERT	WH	GEC	G WIMPEY (WH), DONG AH	1970-1978
Plant 2	Kori 2	PWR (650)	GILBERT	WH	GEC	WH/GEC	1976-1983
Plant 3	Wolsong 1	PHWR (679)	AECL	AECL	HP	AECL	1975-1983
Plant 4	Kori 3	PWR (950)	BECHTEL	WH	GE	HDEC	1978-1986
Plant 5	Kori 4	PWR (950)	BECHTEL	WH	WH	HDEC	1978-1986
Plant 6	Yonggwang 1	PWR (950)	BECHTEL	WH	WH	HDEC	1979-1987
Plant 7	Yonggwang 2	PWR (950)	BECHTEL	WH	WH	HDEC	1979-1987
Plant 8	Ulchin 1	PWR (950)	AREVA5	AREVA	ALSTOM	DONG AH, DHI&C	1981-1990
Plant 9	Ulchin 2	PWR (950)	AREVA	AREVA	ALSTOM	DONG AH, DHI&C	1981-1990
Plant 10	Yonggwang 3	PWR (1000)	KOPEC/S&L	DHI&C/WH	DHI&C /GE	HDEC	1987-1996
Plant 11	Yonggwang 4	PWR (1000)	KOPEC/S&L	DHI&C /WH	DHI&C /GE	HDEC	1987-1996
Plant 12	Ulchin 3	OPR (1000)	KOPEC	DHI&C	DHI&C	DONG AH, DHI&C	1991-1999

Table 5 **First nuclear power plants built in Korea. Integrated from (Park, 1992) (Sung and Hong, 1999) (JAIF, 2003) (Scientech, 2010) (Industcards, 2011 b)**

Plant	Net capacity (MWe)	Date of order	Owner/ Utility	AE	NSSS supplier	TG supplier	Constructor
Mihama-1	320	1967	Kansai EPCO	Kansai EPCO/ Gilbert	WH/MHI	MH	Maeda/Kum/ Obay
Mihama-2	470	1968	Kansai EPCO	Kansai EPCO/ MHI	WH/MHI	MHI	Maeda/Kum/ Obay
Genkai-1	529	1969	Kyushu EPCO	MHI	MHI	MHI	Obay/various
Takahama-1	780	1970	Kansai EPCO	Kansai EPCO/ Gilbert	WH/MHI	MHI	Maeda/Haz/ Taisei
Takahama-2	780	1970	Kansai EPCO	Kansai EPCO/ MHI	MHI	MHI	Maeda/Haz/ Taisei
Mihama-3	780	1972	Kansai EPCO	MHI	MHI	MHI	Hazama/ Takenaka

Table 6 **First PWR nuclear power plants built in Japan. Elaborated from (JAIF, 2003) (Scientech, 2010) (WNA, 2011 a) (Industcards, 2011 c)**

Reactor	Net capacity (MWe)	Date of order	Owner/ Utility	AE	NSSS supplier	TG supplier	Constructor
Tsuruga-1	341	1965	JAPC	EBASCO	B&W/Hitachi/ GE	GE/Toshiba	Takenaka/ Kumagai
Fukushima I-1	439	1966	TEPCO	EBASCO	GE/Toshiba (IHI)	GE	Kajima/various
Shimane-1	439	1966	Chugoku EPCO	Hitachi	Hitachi	Hitachi	Kajima/Taisei/ Goyou/Maeda/ Kumagai
Fukushima I-2	760	1968	TEPCO	EBASCO	GE/Toshiba (IHI)	GE/Toshiba	Kajima / Kumagaiz
Fukushima I-3	760	1970	TEPCO	Toshiba	Toshiba/IHI	Toshiba	Kumagai/ Kajima
Hamaoka-1	515	1971	Chubu EPCO	Toshiba	Toshiba (IHI)	Hitachi	(various)
Tokai-2	1060	1971	JAPC	EBASCO	GE	GE	Shimizu/ Kajima
Fukushima I-4	760	1972	TEPCO	Hitachi	Toshiba/IHI/ Hitachi	Toshiba	Kajima/various

Table 7 **First BWR nuclear power plants built in Japan. Elaborated from (JAIF, 2003) (Scientech, 2010) (WNA, 2011 a) (Industcards, 2011 c)**

(Sung and Hong, 1999) (Roche, 2011). KEPCO E&C started achieving capabilities from the detailed design along with Bechtel during the project to build the 4th, 5th, 8th and 9th Korean plants. Basic design was then obtained along with S&L through Technology Transfer in plants 10& 11. So the total experience to achieve self-reliance went from plant 4 to plant 11 (Table 5) (Sung and Hong, 1999).

The situation is different in the French scenario, since the French Nuclear Power Program was based on the multiple-package contract approach. EDF achieved detailed engineering with

Plant	Net capacity (MWe)	Date of order	Owner/ Utility	AE	NSSS supplier	TG supplier	Constructor
Ginna	581	1965	RG&EC	GILBERT	WH	WH	BECHTEL
Indian Point 2	1025	1965	ENTERGY N	UE&C	WH	WH	UE&C
Turkey Point 3	693	1965	FPL	BECHTEL	WH	WH	BECHTEL
Diablo Canyon 1	1122	1966	PG&E	PG&EC/ BECHTEL	WH	WH	PG&E/BECHTEL
Fort Calhoun	482	1966	OPPD	G&H	WH	GE	G&H/D&R
H.B. Robinson 2	710	1966	PROGRESS	EBASCO	WH	WH	EBASCO

Table 8 **First PWR (Pressurized water reactor) nuclear power plants built in USA. Elaborated from (JAIF, 2003) (Scientech, 2010) (WNA, 2011 a) (Industcards, 2011 d) (Industcards, 2011 e) (Industcards, 2011 f) (Industcards, 2011 g) (Industcards, 2011 h) (Industcards, 2011 i) (Industcards, 2011 l) (Industcards, 2011 m) (Industcards, 2011 n) (Industcards, 2011 o) (Industcards, 2011 p)**

Plant	Net capacity (MWe)	Date of order	Owner/ Utility	AE	NSSS supplier	TG supplier	Constructor
Nine Mile Point 1	621	1963	CNG	NIMO	GE	GE	SHAW/NIMO
Oyster Creek 1	615	1963	AMERGEN	B&R	GE	GE	B&R
Dresden 2	867	1965	EXELON N	S&L	GE	GE	UE&C
Pilgrim 1	685	1965	ENTERGY N	BECHTEL	GE	GE	BECHTEL
Browns Ferry 1	1040	1966	TVA	TVA	GE	GE	TVA

Table 9 **First BWR (Boiling water reactor) nuclear power plants built in USA. Elaborated from (JAIF, 2003) (Scientech, 2010) (WNA, 2011 a) (Industcards, 2011 d) (Industcards, 2011 e) (Industcards, 2011 f) (Industcards, 2011 g) (Industcards, 2011 h) (Industcards, 2011 i) (Industcards, 2011 l) (Industcards, 2011 m) (Industcards, 2011 n) (Industcards, 2011 o) (Industcards, 2011 p)**

the help of subcontractors (Roche, 2011). Regarding Japanese companies (like Hitachi, Toshiba and Mitsubishi) there is evidence of a relatively shorter time-to-market for the AE role, since relationship with foreign suppliers were limited to one or two plants, usually FOAKs of this size series (Table 6 and Table 7).

Considering the US Case Study, The Shaw Group is an important example of instantaneous entry. The acquisition of S&W (S&W, 2011) (The New York Times, 2000), previously experienced on such projects in USA (Table 8 and Table 9), enabled Shaw to enter the market. The costs to become an AE are difficult to estimate, since Technology Transfer and learning by doing techniques are often involved. The lack of information about Technology Transfer costs and license costs does not permit further analysis.

NSSS supplier

The topic is similar to the AE one but the discussion must be detailed in terms of NSSS design and NSSS manufacturing. Korean Case Study is the main source of information about Technology Transfer process for NSSS design (plant 4 KAERI started developing NSSS design capabilities through Technology Transfer and learning-by-doing processes). According to Table 5, self-reliance was achieved at the time of Plants 10 & 11, through a strong agreement with CE (now WH) that brought KAERI to a 95% (Sung and Hong, 1999) share of NSSS design in 1995. Information on NSSS manufacturing shows that a similar path was followed by local manufacturers (Hanjung, later acquired by Doosan Group); an 87% share of local participation in NSSS manufacturing were achieved in 1995. DHI&C completed Changwon Plant Site in 1982, with a 13,000 tons press (WNA, 2011 c). In the UAE bid Westinghouse still supplies a 5-7% of components (nuclear design code, RCP, MMIS) for which Korean companies are not self-reliant. Korean government had an important role in this process, signing a bilateral agreement with the U.S.A. and supporting local manufacturing industries with several ad hoc policies (Sung and Hong, 1999).

Focusing on France the NSSS design and manufacturing roles were both undertaken by Framatome (now Areva), with the specialized knowledge acquired through a licensing process. Westing-

Buyer	What	Market	Description	Cost	Year	Reference	Today (2010-GDP deflator)
Shaw	S&W	AE	Shaw acquires S&W	$600m	2000	(The New York Times, 2000)	$749m
Toshiba	WH	NSSS supplier	Toshiba acquires WH	$4.2bn	2006	(Financial Times, 2006) (Toshiba, 2006)	$4.5bn
Areva	Areva-Siemens JV	NSSS supplier	Siemens sells 34% of its JV with Areva	€1.62bn ($2.33bn)	2011	(Nuclear Power Daily, 2011)	$2.33bn
JSW	Pressa	NSSS manufacturing	Hydraulic presse	$ 2 bn	2011	(MPR, 2010)	$ 2 bn
Doosan	Hanjung	NSSS manufacturing	Doosan acquires Hanjung	$257.97m	2000	(Highbeam, 2000)	$322m
Bouygues	Alstom	TG supplier	Bouygues acquires 21.3% of Alstom's stakes from the French Government	€1.26bn ($1.66bn)	2006	(The Guardian, 2006)	$1.78bn
DHI&C	Skoda Power	TG supplier	DHI&C acquires Skoda Power	$633m	2009	(Financial Times, 2009)	$639m

Table 10 **Strategies followed by companies to enter the nuclear market: historic acquisitions considered for estimations. The cash amounts have been converted with a GDP deflator**

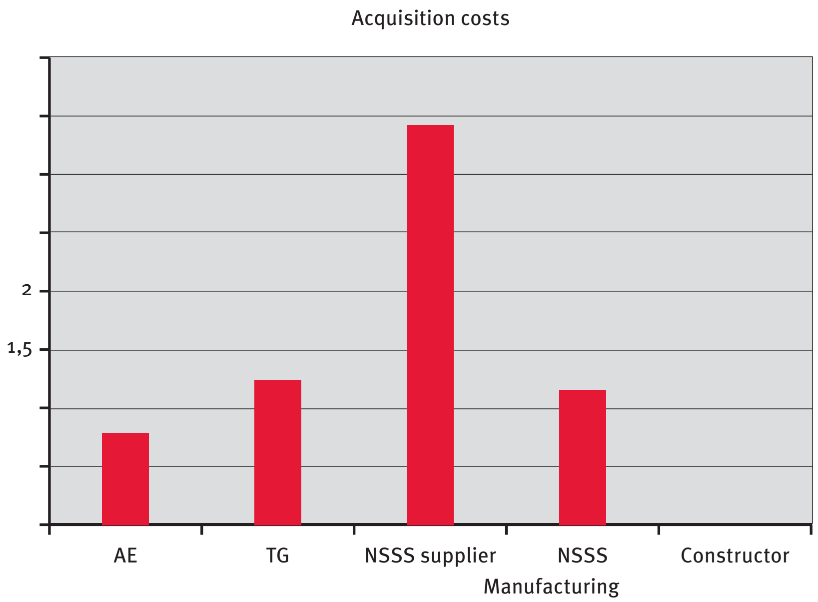

Figure 10 **Mean acquisition costs**

house, the licenser, took part in Framatome establishment in 1958 along with other local companies (Boulin and Boiteux, 2000). Referring to the French Case Study, it is possible to estimate about 7 NPP projects (including the Chooz prototype) needed to Framatome to obtain self-reliance. In 1978 Westinghouse left Framatome shareholding, while the license expired in 1982 (Boulin and Boiteux, 2000). According to (Roche, 2011), companies providing NSSS design and manufacturing were already self-reliant at that date.

A strong involvement of French government, thanks to relevant shareholdings in key nuclear companies (EDF, Framatome), influenced the whole Technology Transfer process (Leny Pellissier-Tanon, 1984) (Golay, Saragossi and Willefert, 1977). Japanese case study shows a shorter lead-time to reach self-reliance in NSSS design and manufacturing for both PWR and BWR technologies (see Table 6 and Table 7). This peculiarity is influenced and connected to the strong governmental support to national nuclear industry for the fossil-fuel independence (WNA, 2011 a) and the R&D efforts by Hitachi, Toshiba and MHI. US' case study gives no useful information. U.S. companies (WH and GE – Table 8 and Table 9) were the "progenitors" of BWR and PWR technologies, developed during and after the WWII, thanks to strong R&D investments (WNA, 2011 b). In addition ASME certifications are needed to supply NSSS components (Voutsinos, 2009) (ONE/TUV/BV, 2009). The cost estimating for the NSSS Technology Transfer, similarly to

Overnight Cost USD/ kWe	Country	Tech.	MWe	Total Cost (million $)	NSSS (million $)	TG (million $)	Constructor (million $)	AE (million $)
3009	Jap	ABWR	1330	4,002	1,027	863	709	680
3382	USA	PWR	1350	4,566	1,172	984	809	776
3860	Fra	EPR	1630	6,292	1,614	1,357	1,115	1,070
1556	Kor	APR1400	1343	2,090	536	451	370	355
1976	Kor	OPR1000	954	1,885	484	406	334	320

Table 11 **Contract values' subdivision: estimates (NEA, 2000) (IEA & NEA, 2010)**

AE, shows a lack of documentation which doesn't permit any further analysis.

TG supplier

NSSS suppliers have a common control over TG prime contracts, reducing the importance and interest of this role for the purpose of this paper. In Korea local companies developed TG suppliers' skills through Technology Transfer process, similarly to the NSSS design and manufacturing (Table 5). In France Alstom was committed with TG supplies since the first NPPs (Table 8), while in Japan the same occurrence regarded MHI for PWR technology. Conventional TG suppliers can operate in nuclear business, since PWR technology has no radioactive fluids flowing into the turbines (Mehta and Pappone, 2008). It is important to highlight a minimum time-to-market for TG suppliers in BWRs (such as Hitachi and Toshiba –Table 6 and Table 7), directly linked to the plant and its technological issues (Mehta and Pappone, 2008). In addition ASME certifications are needed to supply TG components (Voutsinos, 2009) (ONE/TUV/BV, 2009).

Construction

This business appears to be the most interesting prime contractor's role for a newcomer. Most of the countries highlight a strong local participation since first NPP projects. No evidences were found to suggest relevant investments or time-to-entry for this role. A company, according to (IAEA, 2010) must be able to manage the advanced techniques required by the recent tendency of NPP projects to reduce construction schedule. Thus ASME certifications are required for the installation of the equipment (Voutsinos, 2009) (ONE/TUV/BV, 2009). Nevertheless it is important to stress the importance of the "quality first" concept even for this role. (Ruuska et al., 2009) show as "Forssan Betoni", a concrete supplier for Areva in the Olkiluoto 3 project, failing to satisfy the quality standard procured a huge cost over budget and delay to the project. A strategic factor for allowing a firm to enter in the construction market is the reactor size: smaller is the size, easier is to enter (Locatelli and Mancini, 2010). So the strategic assets for firms willing to enter in this role are not the technical capabilities, whereas the skills in quality control and quality assurance. In this role the firms receive the designs from the vendors and AE, so the engineering skills are not really stressed, but it is crucial the correct execution.

Costs to enter the nuclear business and revenues

The final focus is on the costs and revenues: the goal of this section is to provide an order of magnitude for the cost/investment required to enter the nuclear market in one of the roles presented in the previous sections and its expected revenue. Table 10 includes the costs of acquisitions, mergers observed in the Case Studies' developed for the different contractual roles. The role is the key factor in this analysis: on one side the Constructor is characterized by the absence of core-technologies (beside mainly quality certifications) specific for the nuclear industry, on the opposite side the NSSS supplier is the role involving the greater investments.

Figure 10 presents the Mean acquisition costs, evaluated through data elaboration of past acquisitions. Core-technology companies (NSSS suppliers) require the larger amount of cash, according to the companies analyzed. Table 11 and Figure 11 show the project cost estimations according to the different roles. The Construction prime contractors grant a significant share of total project's value. Despite the peculiar specialization required to design and build the elements in the nuclear area (Core, Control road, pumps, heat exchanger etc.) these items account for a minor share of the overnight cost. Most of the overnight cost is related to the Balance Of Plant (BOP) and civil works (e.g. pouring concrete). That is the reason why the "construction" can be so interesting for all the EPC companies.

Conclusions: Answers to the Research Questions

The conclusions of this paper are the answer to the research questions

Q1: Which are the drivers shaping the PDC in a nuclear power plant project?

Since the presence of a national nuclear power program enables national companies to enter the business, the government is the most influencing driver in the shaping of a NPP PDC. As showed in all the countries analyzed

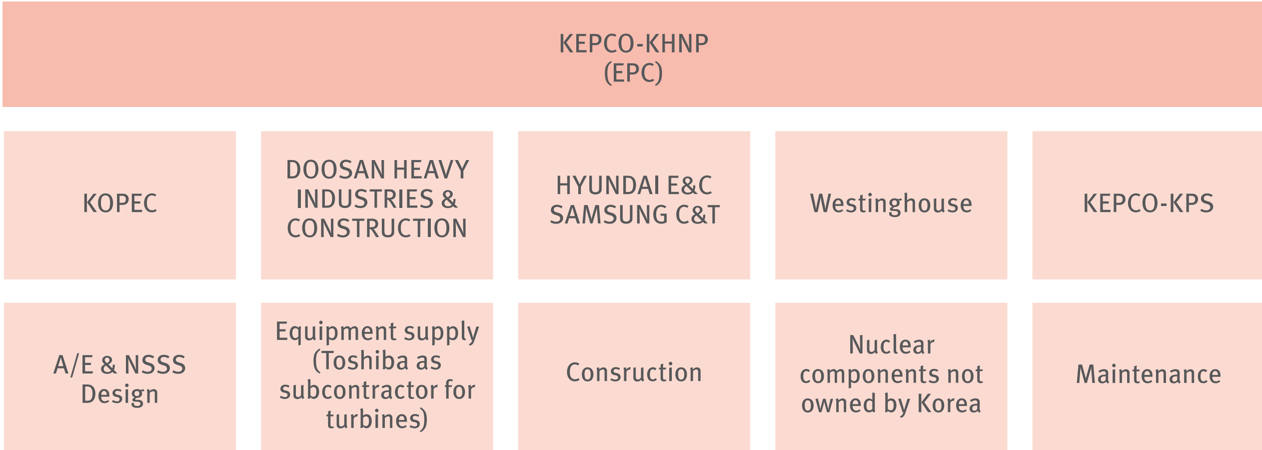

Figure 12 - **Korean Consortium winning in UAE. Elaborated from (Park and Chevalier, 2010) (Berthelémy and Lévêque, 2011)**

the decisions to start the nuclear power program has been taken not by single utilities, but from the "national policy makers" i.e. the national governments. The government drives also the Technology Transfer process, which is basic in order to develop a self-reliant national nuclear industry. Partnerships and alliances are significant drivers, creating opportunities for local companies in participating at NPP projects.

Q2: Which are the main barriers to enter the nuclear power plant business sector?

The support of the national government is the greatest barrier in the nuclear business. In absence of a national nuclear power program, no company can enter nuclear business as a prime contractor. Other barriers depend on the prime contractual role. Technology Transfer processes, investments and partnerships are important to overcome them.

Q3: Which are the enabling factors leading a company to proficiently enter the nuclear power plant business?

Enabling factors for companies can be summarized as: Workforce, Qualifications, Technological know-how. These three factors are required differently for prime contractual roles analyzed: in particular it is remarkable the Qualification's role (ASME Stamps and RCC-M Qualifications are broadly required in NPP projects). Qualifications are required both to manufacturing companies, to construction's prime contractors and NSSS suppliers.

Q4: Do exist Paths, leading to an entry in nuclear power plant PDC?

The case study methodology shows the similarities between strategic paths followed by companies. No evidence has been found of companies directly entered into international nuclear business: the importance of a national nuclear program had been remarked. Furthermore, construction companies generally entered nuclear business after experiences in international projects. NSSS suppliers and AE's prime contractors (roles involving a strong technological know-how) often entered the national nuclear business through Technology Transfer processes and efforts in R&D during the first years after the World War II.

Q5: How much time and investment must a company face to enter nuclear power plant business? Are they different along with diverse contractual roles?

The appropriate way to evaluate required time is the number of participations in NPP projects. Different roles require different time: AE and NSSS suppliers' prime contractors acquired the knowledge through a Technology Transfer process. This route took 6 to 7 NPP project participations (for French and Korean situation) for the NSSS design and manufacturing capabilities and the same for the development of AE skills. Japan developed skills of this kind in a shorter time (about 3 NPP project participations), due to its strong efforts in R&D. Costs connected with acquisitions of companies to enter nuclear business have been analyzed through past acquisitions: NSSS suppliers' invested the higher amounts. Remarkable is that Japanese construction companies participated in national NPP projects since the beginning.

Appendix: Pilot Case Study: UAE's bid for a new NPP project

As shown in (Park and Chevalier, 2010) in 2009 a Korean Consortium, led by the Korea Electric Power Corporation (KEPCO), won a $20 billion contract to develop a civilian NPP for the UAE (one of the World's largest nuclear tenders on offer), beating French, U.S. and Japanese rivals. The Korean Consortium was selected among two other proposals, made by Areva and General Electric-Hitachi, in a decision process strongly affected by price. Figure 12 shows the Korean Consortiums' components in details.

The Korean Standardized Nuclear Reactors (KSNR), leading to the current OPR-1000 and APR-1400 nuclear reactors produced by Korea, are based on the U.S. Combustion Engineering (now Westinghouse) reactor called System 80+. Korea is embarking on a process to become completely self-sufficient for the technologies still supplied by Westinghouse, which include the nuclear design code, the reactor coolant pumps and the man-machine interface systems. This statement highlights the macro-importance of partnerships and strategic alliances in nuclear power business, along with the Technology Transfer process. The Case Study diffusely bases on scientific papers, analyzing reasons that led to the Korean victory. Costs, referring to (Berthelémy and Lévêque, 2011), were one of the most important. The APR1400, at the time in construction phase, in Korea had an overnight cost estimate about 60% less expensive than the EPR in construction in France by Areva, and 32% less expensive than the EPR and AP1000 in construction in China. The paper then defines other parameters important for the winning bid: shutdown performances and contract risks allocation are examples of effective factors.

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