

# Evolution of UK Contract Structure for Nuclear Power New Build

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# Evolution of UK Contract Structure for Nuclear Power New Build

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## Introduction

The first UK programmes of nuclear power projects launched in 1956 employed consortia of engineering and construction contractors competing to develop a series of one-off designs developed from the government's Calder Hall prototype. The ownership, size, strengths and financing today of the utilities, engineering contractors, their suppliers and supporting expert organisations for designing and constructing new nuclear power stations in the UK have changed greatly since the start of those first projects sixty years ago. Unchanged is the dependence of today's new projects on bespoke engineering and construction and therefore the value of lessons to be learnt from how engineering and construction contractors were employed in those previous programmes.

## Contract Structure for the Magnox Programme (1956-1971)

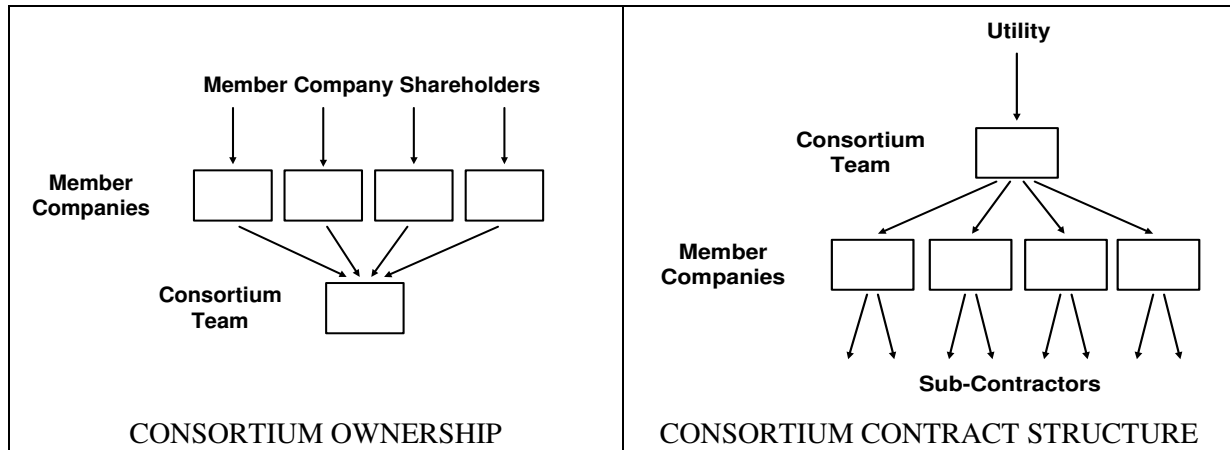
The UK government's civil nuclear power programme in 1966 had three objectives: UK energy independence, export sales and defence requirements for plutonium.<sup>1</sup> UK energy independence meant that design of the projects would be developed from the 50 MWe reactors operating at Calder Hall, Windscale, using natural uranium fuel. Export sales meant that the projects should be designed to try to attract export orders. Defence requirements meant that the new power stations were to produce plutonium as well as commercial power. The plan was to invest in a series of Magnox-fuelled stations totalling 5000 MWe capacity by 1965, later increased to 6000 MWe, over and above the capacity of the Calder Hall and repeat reactors being built at Chapelcross.

The government's research and development organisation the UK Atomic Energy Authority (UKAEA) was the designer and operator of the Calder Hall reactors. The nominal customers to buy and operate the new Magnox power stations were two newly-reformed state-financed utilities - the Central Electricity Generating Board (CEGB) and the South of Scotland Electricity Board (SSEB). These two utilities had then little or no experience of large projects or nuclear power. On advice from the UKAEA, the government in 1954 encouraged UK heavy electrical plant manufacturing companies to invite boiler maker companies to join them to form consortia that would have the engineering and commercial strength to develop designs scaling up from the Calder Hall prototype in order to compete to be contractors supplying complete power stations. Four such consortia were formed in 1954.<sup>+</sup>

The concept of a consortium of companies acting collectively as a contractor responsible for designing and delivering a complete project was unusual in the UK, though some of these companies had worked that way to engineer and build large projects in Commonwealth countries. The business model for the Magnox projects was that a consortium would tender to a utility for a 'turnkey' contract to supply a complete power station. If a consortium's tender resulted in a contract the work for the delivery of the power station would be divided amongst the consortium's member companies. The member companies in each consortium were thus to be liable for a whole contract and also to be sub-contractors to an organisation they owned.

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<sup>+</sup> The names of the consortia and later changes are listed the end of this paper.



Comparison of Ownership Relationships and Contract Structure in a Consortium

The UKAEA had the roles of leader in research and development of reactor systems, operator of the Calder Hall and various experimental nuclear installations and advisor to the government and utilities. It was also the national nuclear safety authority, until this function was branched off in 1959 as an independent inspectorate. Though in competition for projects, the consortia shared agreed research and development programmes coordinated by the UKAEA. The first senior staff of the four consortia attended courses in reactor technology run by the UKAEA, and some were seconded to the construction of the Calder Hall or repeat reactors at Chapelcross. The UKAEA and the consortia were thus the dominant influences on the engineering and management of the Magnox programme.

Three coastal sites in England and one in Scotland were agreed by the utilities and UKAEA for the first Magnox power stations. In 1956 each of the four consortia tendered a design that was subject to adaptation to any of these sites. Three tenders were accepted. The three accepted tenderers then proceeded in parallel to execute their projects. The other consortium was required to revise its design and to establish a “proper HQ project” organization. A contract was then negotiated for that consortium to proceed with the fourth project. By the end of 1957 each of the four consortia were thus committed to their first project.<sup>2</sup> The terms of payment were fixed price but adjusted for inflation, the costs of design changes to suit the site allocated and to adapt to new nuclear data from the UKAEA. Payment was in instalments according to progress of work.

A further consortium then appeared, APC, similar to the original four in being formed by an electrical plant manufacturer and a boiler maker. When the CEGB invited tenders for the next Magnox project APC offered a lower price and so won that contract. In the next four years a further four new Magnox stations were ordered from the other consortia.<sup>3</sup> Project by project these included substantial advances in reactor power, notably by using a concrete instead of steel reactor pressure vessel achieving 495 MWe per reactor. The UK Magnox programme from 1956 to 1971 thus consisted of nine projects all different in reactor design and with a total capacity of 4260 MWe.<sup>4</sup>

In operation the Magnox projects became ‘work horses’ supplying the UK base load demand for power from 1963 to 1973. All nine continued in operation well past their designed life. In a review of the first ten years operation of the stations the CEGB commented favourably on their performance and reliability. The reliability and availability problems encountered were more in their non-nuclear systems.

### The Bradwell Project

The Bradwell project was one of the first three of its class of Magnox projects. That project is selected here as it is well recorded and its consortium went on to deliver the most projects.<sup>5</sup>

The NPPC consortium contracted with the CEGB to design and build the Bradwell project. Six companies were members of that consortium. Three of these companies had been contractors supplying main mechanical and electrical plant and services for the Calder Hall project.

NPPC created an initially small central engineering and supporting team of individuals seconded to it from the consortium's six member companies, most relatively young staff with limited experience of their parent companies' businesses. The Chairman of the biggest of the NPPC member companies took the time to lead the consortium well into the execution of the Bradwell project, supported by a general manager who had been leader of a team employed to coordinate the contractors for the Calder Hall project. Engineering and commercial staff were added to prepare the first tender, and then more for engineering, construction and managing the Bradwell contract, new studies and tendering for further projects. After the small team seconded from the member companies most staff were recruited from other engineering industries and research organizations.

When inviting tenders from the consortia the customer the CEGB had not specified the station capacity required. Each consortium's embryo engineering team had the task of proposing the capacity and form of reactor-boiler-turbo-generator power and safety systems, fuel-handling processes and supporting services for a complete power station. Their proposals for scaling up from the 50 MWe Calder Hall reactors and optimizing the power system to achieve high thermal efficiency were governed by limits to fuel temperature and size of pressure vessel.<sup>6</sup> Data on fuel, moderator and heat transfer was dependent upon the operation of the Calder Hall reactors and continuing experimental work. The choice made by NPPC for Bradwell was to scale up to 150 MWe per reactor.<sup>7</sup> Detailed design decisions had to be made before final supporting test information was available, so that changes were required before tendering and during the contract. Two major innovations were design to achieve natural circulation of the CO<sub>2</sub> coolant sufficient for shutdown heat removal and the provision of a system for re-fuelling the reactors while operating at full power.

The detailed engineering decisions were conservative, for instance in the reactor pressure vessel stressing. Innovation was avoided when not needed to scale up from Calder Hall, for instance in choosing to use six turbo-generator sets of a size proven in use elsewhere. The design policy was that the reactor structures should be simple. They were compact, running the risk that space governed the critical path for installing and proving the reactor services, instrumentation and control systems.

Procurement and construction was the responsibility of the member companies of the consortium, employing many of their usual suppliers but having to educate some without experience of Calder Hall in the nuclear requirements for quality assurance and clean conditions control in plant installation. In its role as main contractor the consortium was responsible for planning construction, site management, supervising each member company's work and providing some shared services. Construction innovations at Bradwell were the erection of a temporary goliath crane straddling the twin-reactor site so as to be able to install large pre-fabricated pressure vessel and boiler sections, and the use of the waterside location to enable the delivery of large items to the site by boat. The consortium set up a pre-commissioning team responsible for handing over the completed station to the utility.

Their isolated sites away from industrial and major construction installations meant that the construction of the Magnox projects was not much affected by the UK's then poor industrial relations, with the exception of the first Scottish site not far from Clydeside. Bradwell was completed the year after planned, delayed by design changes, some due to new nuclear data, and problems with reactor control components in commissioning. This compared well with other large industrial UK projects at that time.

One result of the advances in power per reactor achieved by the consortia designs was the prospect that fewer projects would be needed. Following discussion with the CEGB the AEI/JT and NPPC consortia amalgamated to become TNPG.

## **Contract Structure for the Advanced Gas-Cooled Reactor Programme (1965-1988)**

The use of Magnox fuel had been dictated in 1955 by the policy of UK energy independence and the then lack of uranium enrichment plant. The price was the large physical size and therefore high capital cost of the reactors and limits to thermal efficiency set by the maximum Magnox temperature. In 1964 the government decided that further nuclear power stations were required in succession to the Magnox programme. Development of UK capacity for uranium enrichment enabled the UKAEA to study many alternative types of higher temperature reactors, including light water cooled systems already coming into use in the USA and then in France. The UKAEA built some prototypes of several very different systems. At Windscale the UKAEA built a prototype of 'Advanced Gas Cooled Reactor' (WAGR) of 33MWe capacity using enriched fuel to operate with CO<sub>2</sub> at much higher temperatures and so achieving better thermal efficiency while utilising engineering expertise from the Magnox projects. While national debates continued about choosing between the various alternatives, the UKAEA commissioned a design study of developing the WAGR up to commercial scale of power generation. The UKAEA employed the APC consortium on this study as APC had stated that they would be withdrawing from new nuclear projects.<sup>8</sup>

The other two interested consortia BNDC and TNPG\* had welcomed the UKAEA's suggestion of developing the higher temperature reactors for future power projects. They had been given only a watching role in the WAGR prototype. Each began its own separate studies of possible AGR designs, as well as continuing studies of light water and other alternative types of reactors.

For the new programme of power station projects the UKAEA and the CEGB converged on a choice between developing the AGR concept or adapting one of the US light water reactor systems. At that point APC re-entered into competition with BNDC and NPPC. The competition became openly controversial as APC were allowed to tender on the basis of an outline design for an AGR station using a form of fuel element developed by the UKAEA potentially more suitable than used in the WAGR prototype.<sup>9</sup> The CEGB and UKAEA chose the APC's AGR proposal.<sup>10</sup> It was heralded by the UK government as an economic breakthrough.

### **The Dungeness B AGR Project**

APC's proposal was thus chosen in 1965 as the first of the UK's programme of Advanced Gas-cooled Reactor power stations. The designated site was Dungeness B, alongside an operating Magnox station.

APC's outline design was based on scaling up from the WAGR 33 MWe prototype to 615 MWe per reactor and using the new form of fuel element.

The terms of contract for this first AGR project were similar to those followed through the Magnox programme.

After a year a series of major engineering problems became apparent in developing from the outline design, particularly with the reactor pressure vessels and core, boilers and gas circulating system. These required much re-design and the replacement of major parts. By then the reactor building structures were partly built. Reinforcement of the APC engineering leadership from the UKAEA WAGR team was too late.

The change to an untested form of fuel element was not the main cause of the failure of the outline design. The failure was that the reactor design was an outline, lacking sufficient study of the engineering and construction of reactor and boiler systems before commitment.

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\* The EE/BW/TW consortium had then become BNDC – see list of acronyms at the end of this paper

In addition to the direct costs of removing and replacing large components, the financing costs of the incomplete Dungeness B work led to the end of APC as a business and big losses to its member companies. APC ceased trading in 1969 and was acquired by the CEGB.

After financial advice not to abandon the project, the CEGB employed the BNDC consortium and UKAEA staff to re-engineer the design and GEC to manage the completion of the project. Further problems were encountered in continuing its construction. With a strengthened project team and the employment of contractors with experience of Calder Hall and several Magnox projects the re-engineering produced a working power station, but completed 13 years behind its original schedule. The other two consortia had meanwhile proceeded with developing their different AGR designs and then tenders for AGR projects for the CEGB and SSEB. Though also delayed by reactor and boiler engineering and construction problems, three of their AGR projects were completed before Dungeness B.

APC had been formed as a managing contractor with only a small engineering team, intended to give its member companies the responsibility for engineering all the packages of work for a project. APC's most influential leaders came from the UKAEA. Its member companies did not have experience of contributing to the Calder Hall or first Magnox projects. APC had started the design of their Magnox project when published information was available on the other consortia's projects. From this they had the experience of competing more by price than by engineering. When starting work on its AGR proposals APC did not have the experience of the other consortia of scaling up from a prototype.

The APC management team was disbanded after the collapse of the company. Their engineering and support team were retained for the completion of Dungeness B. Some of those remaining moved to the final combination of staff from the other two remaining consortia that were brought together to form the National Nuclear Corporation (NNC). In this NNC became an engineering and project management services company.<sup>11</sup> It ceased to represent a consortium of companies and became free to trade independently.

During the Magnox and AGR programmes the CEGB and the SSEB had become powerful state-owned state-funded organisations.<sup>12</sup> Under their direction the NNC became the management contractor for the completion of the last projects in the AGR programme.<sup>13</sup>

### **Contract Structure for the First UK PWR Programme (1987-1995)**

Disappointment with the cost and performance of the AGRs and renewed concerns about the future availability of energy supply led the government and the utilities to reconsider alternative types of reactor, particularly those in operation elsewhere. A review of the choices was commissioned from the NNC. The objective was to assess which designs should be considered for the UK's next programme of power stations.

The review selected two alternatives to further AGR projects. Neither were gas-cooled systems. One was to develop the UK's 'SGHWR' heavy water primary circuit system. For this the UKAEA had built a prototype. The other was the PWR pressurized water-cooled system already in use by several commercial utilities in the USA and the French state-owned national utility. By comparison, the SGHWR system existed only in prototype and would require a programme of development. As a result the UK government and CEGB agreed on the choice of the PWR system for their programme of new power station projects.

### **The Sizewell B Project**

The site chosen for the UK's first PWR project was Sizewell, alongside a completed Magnox station. A series of repeat projects was expected. None followed this first one because of cheaper energy



from off-shore gas.

The design policy was that Sizewell B should be based upon the proven PWR technology. Experience of several projects completed in the USA had led Westinghouse and Bechtel to advocate their PWR design as the 'SNUPPS' Standardized Nuclear Power Plant System. No scaling up was required for Sizewell B from those US projects, but the SNUPPS design was not followed without changes. Applying UK principles for safety analysis developed in the Magnox and AGR programmes and lessons from reactors stations operating in the USA led to additions to reactor instrumentation, control and safety systems, secondary containment, and replacement of boiler material. The normally duplicated station service, control and safety systems were quadrupled, and the operating systems and structures became more complex to meet a UK code for seismic resistance. To suit supplying the UK national grid the station was also different to those in the US in having two turbo-generators fed by parallel steam lines rather than one.<sup>14</sup>

A series of safety studies and detailed safety case with all these changes for the Sizewell B project was submitted to the UK's independent national inspectorate. The project to build the project was then subject to a public planning inquiry. These approvals to proceed to execute the project were completed in 1987, amounting to a total of six years of 'pre-project' preparation after selection of the type of reactor. In this time much of the engineering was completed to provide detail for planning procurement and construction. Detailed information of requirements was the basis for a major campaign to achieve quality of components and services from the many potential suppliers that lacked recent experience of nuclear work.

Applying their experience from the AGR programme and also its non-nuclear major projects the CEGB directed and managed the project. The CEGB thus took on the role of being their own managing contractor. They appointed a project director and a project supervisory board accountable to the CEGB Board of Directors. The engineer appointed to be the project director had led the project through the preparatory work. Following the structure evolved to complete the AGR programme the CEGB put together a unified dedicated NNC and CEGB project team with Westinghouse and Bechtel staff initially embedded in the team. The project team was required to plan and manage the work in detail. At one time the team was three times larger than the NNC strength inherited from the AGR programme.

The CEGB employed Westinghouse as contractor for the reactor primary system, with a negotiated contract. The contracts with others for construction and electrical, mechanical and control systems were fixed price contracts except that quantities were the basis where design was incomplete or the work was dependent on other conditions such as access. All these contractors were required to join a combined planning team.

The UK electricity supply Industry was privatised during the project, but the direction and organisation of the project were sustained through several subsequent changes in ownership and financing. The project was completed two months ahead of the target date proposed in the business case.

Sizewell B was expected to be the first of a programme of PWR projects. Charged to it was the cost of all the pre-project work that could have been shared with repeat projects.

### **The UK Nuclear Power Programmes from 1954 - Summary**

The civil power industry was deliberately spawned by the government out of its military defence policy. This unusual initiation of a new industry was achieved by the unusual structure of inviting the UK's heavy electrical, mechanical and civil engineering companies to form consortia to compete to bid for turnkey contracts to engineer and construct new commercial scale nuclear power stations.

The government's initial objectives for the Magnox and AGR programmes were achieved, but when judged only as power stations the projects were costly and only initially had some export value. All three programmes had the common objective of supplying power to the national electricity utility but underlying the Magnox and AGR programmes was an undeclared policy of continuing development project by project rather than establishing an economic standard.

Formation of consortia of the electrical and mechanical engineering heavy engineering companies had no obvious precedent from government projects or the companies. This procurement path was sustained into the second series of projects. It started with momentum from commitment to nuclear power as a national necessity. It was the effective structure through the Magnox programme. The UK government, its agencies the UKAEA and CEBG and the companies were locked into this initial structure at the start of the AGR programme. It decreased in need and effectiveness as the CEBG gained engineering and managerial authority. As observed other countries' early nuclear programmes, the first structure chosen was an initially unchallenged framework of mixed interests and consequently mixed success.<sup>15</sup>

The consortia varied in managerial strategy. One initially formed by a potentially strong collaboration of complementary engineering companies but weakly linked was required to establish effective project management and was then successful. One initially formed as a management organisation but weak in engineering was reinforced too late to remain in business.

The four original consortia each gained the experience of scaling up reactor size from the Calder Hall model. The Bradwell Magnox reactor capacity of 150MWe was scaling up from Calder Hall 50MWe reactor design by a factor of 3. For the Dungeness B AGR 615MWe scaled up from the 33MWe WAGR by factor of 18. For the Sizewell B PWR zero. The Dungeness B project should clearly have not been scaled up so much unless as a commercial prototype testing all ideas from a pilot plant. The combined efforts of the other consortia supported by the CEBG in re-engineering to rescue the Dungeness B project were an engineering triumph for the consortium and UKAEA team employed in place of APC.

At the start of the Magnox and AGR programmes the UK government and its agencies decided how much and how to invest in new power generation. Its agency the UKAEA initiated the reactor technology and they enabled UK heavy engineering companies to develop the expertise to compete to supply new nuclear power projects. 40 years later there had been complete changes in the roles and ownership of the utilities, the engineering companies and the nuclear authorities. Alternative sources of energy became too competitive and the total home demand for nuclear and non-nuclear power stations was not a big enough market for the engineering companies. Privatisation of the UK utilities brought to an end the government's role as the investor in new power projects and their interest in advancing nuclear power technology. The engineering companies merged and much of their power plant manufacturing capacity closed or became parts of international businesses. The only continuity was in the consortia project teams from the first Magnox projects through to Sizewell B. Their experience in engineering and managing the nuclear power projects came together into the one national organisation, NNC, that was finally acquired by Amec.

## **UK Nuclear New Build Now**

The UK government is now committed to a regulated commercial market. The government is at political risk if power supplies fail, but it is the utilities and their backers that now decide whether to invest in the new projects needed to supply power. In the 'Western' world only in the US, France and Japan have the home markets been large enough to support national contractor businesses supplying nuclear power station systems, in France state-owned. A few international contractors have the engineering and commercial strength to offer to supply new nuclear power reactor systems to the standards set by government regulators. None are dependent on the UK market. Decommissioning is now the main nuclear work for UK companies. The supply of new nuclear power projects has



become an international business, as is the procurement of projects in oil & gas, mining, aerospace and other industries.

The UK's previous nuclear programmes demonstrate that investors in a project can satisfy multiple objectives only at a price. The risks of doing so remain. The UK government now wants utilities to supply power, with regulation, and to do so competitively but promising that more than half of new build will employ UK resources and help develop exportable services and products. The normal commercial mode of the utilities and their investors is priority to speed of completion to start earning a return on capital cost.

From early in the Magnox programme the CEGB and other UK promoters displayed interest in learning from their experience of managing major nuclear and non-nuclear projects. They were at first shocked when they took part in independent studies that demonstrated that late completion and cost overruns were mainly due to their own inadequate attention to engineering, resources and risks before authorising the execution of a project.<sup>16</sup> The success of Sizewell B was based on these lessons and the choice of developed technology. That project was most subject to public safety and economic questions. Prior agreement of detail with contractors and the regulator is the clear need for delivery on time. The lengthy public inquiry gave time to prepare Sizewell B in detail. The success of that project in proceeding through construction into commissioning and operation within its target time supports the growing argument of experienced project managers and analysts of the value of 'pre-project shaping' capital-intensive projects to rid them of institutionally caused internal risks before authorising contractors to start their execution.<sup>17</sup>

### **The UK Nuclear Engineering Consortia**

AEI/JT	AEI and John Thompson consortium, formed in 1954, merged with NPPC in 1960 to form TNPG
APC	Atomic Power Constructors Ltd, formed in 1957 by Crompton Parkinson, Richardsons Westgarth, International Combustion and Fairey Engineering Ltd
BNDC	British Nuclear Design & Construction Ltd, successor to EE/BW/TW, formed in 1965
EE/BW/TW	English Electric Co., Babcock & Wilcox and Taylor Woodrow consortium, formed in 1954, reformed in 1965 as BNDC
GEC/Simon-Carves	The UK General Electric Co. and Simon-Carves Ltd consortium, formed in 1954.
NNC	National Nuclear Corporation, formed in 1973 by merging TNPG and staff from the UKAEA and BNDC
NPPC	The Nuclear Power Plant Company consortium, formed in 1964 by C A Parsons, Reyrolle, Whessoe, Head Wrightson, Clarke Chapman, Strachan & Henshaw, Sir Robert McAlpine and Alexander Findlay. Merged with AEI/JT in 1960 to form TNPG
TNPG	The Nuclear Power Group consortium, formed in 1960 by the merger of AEI/JT and NPPC
UPC	United Power Co, formed by APC and GEC/Simon-Carves 1961-1964

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### **Author**

Stephen Wearne was the first mechanical construction engineer on site at Bradwell. He moved to the GEC/Simon-Carves Atomic Energy Group as reactor engineering coordinator for Hunterston and then Project Engineer for Tokai-Mura. He is now a tutor for industrial executive courses in engineering management and project management run by the School of Mechanical, Aerospace and Civil Engineering at the University of Manchester. He is Emeritus Professor of Technological Management, University of Bradford. He is author and

co-author of books and papers on project organisation, engineering contracts, joint ventures and urgent and unexpected projects. He was co-author with R H Bird of the report 'UK Experience of Consortia Engineering for Nuclear Power Stations' published by the Dalton Institute in 2009.

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- <sup>3</sup> Because of the limited prospect of further projects the AEI/JT and NPPC consortia merged in 1960 to become TNPG
- <sup>4</sup> NPPC also obtained an export contract for a Magnox reactor station at Latina in Italy, constructed with local partners. GEC/Simon-Carves similarly obtained an export contract for a Magnox reactor station at Tokai Mura in Japan, constructed with local partners
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- <sup>7</sup> Net electrical power supplied by each power station depends upon thermal efficiency, station consumption and also some reductions in operation below design capacity to reduce wear and tear risks
- <sup>8</sup> In 1961 the GEC/Simon-Carves and APC consortia formed a joint consortium the United Power Co. but never combined their strengths. They separated in 1964. GEC/Simon-Carves also decided not to offer any new nuclear projects
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## Evolution of UK Contract Structure for Nuclear Power New Build

### Three Firsts of a Class of UK Nuclear Power Station Projects

	<b>BRADWELL</b>	<b>DUNGENESS 'B'</b>	<b>SIZEWELL 'B'</b>
Location	Essex coast. The only industrial development in an otherwise non-industrial area.	Kent coast. Adjacent to operating Magnox power station in otherwise non-industrial area.	Suffolk coast. Adjacent to an operating Magnox power station in otherwise non-industrial area.
Nuclear reactors	Twin CO <sub>2</sub> cooled reactors using natural uranium Magnox fuel.	Twin Advanced Gas-cooled Reactors (AGR) using enriched uranium fuel.	One Pressurised Water Reactor (PWR) using enriched uranium fuel.
Reactor capacity	2 x 150MWe	2 x 615 MWe	1 x 1198 MWe
Date of start of project execution	1957	1965	1987
Expected date to begin commercial operation	1961	1970	1994
Actual date began commercial operation	1962	1983	1995
Budget capital price	£45m	£89m	£1691m
Capital cost when began producing full power	£50m	£685m	£2030m