



CANDU NUCLEAR REACTOR TECHNOLOG .

B. K. Kakaria
AECL CANDU

ÖZET

AECL nükleer alanda, 40 yıldan fazla deneyime sahiptir. Özgün Kanada nükleer teknolojisi, geçen 20 yılı aşkın sürede, dünyaya açılmıştır. Kanada'daki 22 CANDU reaktörüne ek olarak, iki tane Hindistan'da, bir tane Pakistan'da, bir tane Arjantin'de, dört tane Kore'de ve beş tane Romanya'da bulunmaktadır. CANDU teknolojisindeki ilerlemeler, evrimsel santral iyileştirmelerine dayanmaktadır. Söz konusu ilerlemeler, ileri nükleer güç programına destek olmak üzere, sistem performans iyileştirmelerinden oluşmaktadır. CANDU santrallerinin sahip olduğu iyi performans düşünüldüğünde, CANDU işletme deneyiminin yeni ve eskinin tekrarı olan tasarımlara yansıtılması önemli görülmektedir.

ABSTRACT

AECL has over 40 years of experience in the nuclear field. Over the past 20 years, this unique Canadian nuclear technology has made a worldwide presence, In addition to 22 CANDU reactors in Canada, there are also two in India, one in Pakistan, one in Argentina, four in Korea and five in Romania. CANDU advancements are based on evolutionary plant improvements. They consist of system performance improvements, design technology improvements and research and development in support of advanced nuclear power. Given the good performance of CANDU plants, it is important that this CANDU operating experience be incorporated into new and repeat designs.

INTRODUCTION

Working towards the establishment of the nuclear power program in Turkey is not new to AECL. In mid 1980s AECL's negotiations with TEK led to the signing of a contract for the first unit. The project however, did not proceed as a result of difficulties associated with the financing of the build-operate-transfer model.

Once again AECL has responded to latest requests for proposals for Akkuyu by TEK and is actively pursuing this project. The present Forum is therefore timely to provide input to these deliberations.

WHAT IS AECL

AECL has over 40 years of experience in the nuclear field. It was formed in 1952 as a Crown Corporation, wholly owned by the Government of Canada. Responsible for developing peaceful uses of nuclear technology in the areas of electricity generation, health applications and food preservation. In the field of electricity generation the efforts led to the development of CANDU nuclear power system.

The initial commercialization of the CANDU system was based on a partnership between AECL, Ontario Hydro and Canadian Industry. The successful CANDU program in Canada, led to its expansion into the export markets.

CANDUs AROUND THE WORLD

Over the past 20 years, this unique Canadian nuclear technology has made a worldwide presence. In addition to 22 CANDU reactors in Canada, there are also two in India, one in Pakistan, one in Argentina, four in Korea and five in Romania.

CANDU FAMILY

There are currently three sizes of CANDU units :

CANDU 6, of which there are 12 units operating and under construction. The gross output of CANDU 6 is approximately 700 MW. Over the past 10 years, the four operating CANDU 6 units have achieved average lifetime capacity factors higher than 80%;

CANDU 3 is our latest design which is over 70% complete. It embodies the next generation technology including computer based engineering tools, simplified design but using proven components, upfront licensing, modular construction techniques, proven components and short construction duration. The output of CANDU 3 is 450 MW;

CANDU 9 is the 950 MW size. 12 units of CANDU 9 are operating in the multi-unit configuration in Ontario. A single unit version of the 950 MW size is being developed from this reference.

CANDU 6 PROJECTS

CANDU 6 is an up-to-date product which is currently under construction for commissioning even beyond the turn of the century.

Four CANDU 6 units are presently in operation :

- Wolsong-1 in Korea (in service 1983)
- Embalse in Argentina (in service 1984)
- Gentilly-2 in Canada (in service 1983)
- Point Lepreau in Canada (in service 1983)

In Romania there are five CANDU 6 units under construction at the Cernavoda site. Starting in 1990, the newly formed utility RENEL awarded a contract to an international consortium led by AECL, to provide the Project Management and Construction Management for Unit 1. Unit 1 is presently over 85% complete and is scheduled for criticality in December 1994.

In Korea, in addition to the operating unit there are 3 more units under construction. The containment structure of unit one is already complete and heavy components such as the reactor have been delivered to the site. The site work and equipment orders for units 3 and 4 are already well underway.

Therefore, the CANDU 6 has an up to date reference plant in the Wolsong units now under construction with the first unit scheduled to go in service in 1997. CANDU 6 continues to be a competitive, economic and reliable energy source. The safety and licensing basis aspects have been updated to meet the current regulatory requirements as the new units start operating. CANDU 6 has demonstrated an excellent world leading performance which will be maintained by replication of the design, but will incorporate low risk and proven improvements.

The life time load factors of the four CANDU 6 operating units are as follows :

Point Lepreau (Canada)	90.4%
Wolsong 1 (South Korea)	83.2%
Gentilly 2 (Canada)	67.7% (limited in the early years by low demand)
Embalse (Argentina)	73.3% (limited in the early years by grid restriction)

In the last 5 years, with demand and grid restrictions no longer present, all the units have higher than 80% load factors as shown in table below :

Point Lepreau (Canada)	95.2%
Wolsong 1 (South Korea)	88.1%
Gentilly 2 (Canada)	81.2%
Embalse (Argentina)	88.9%

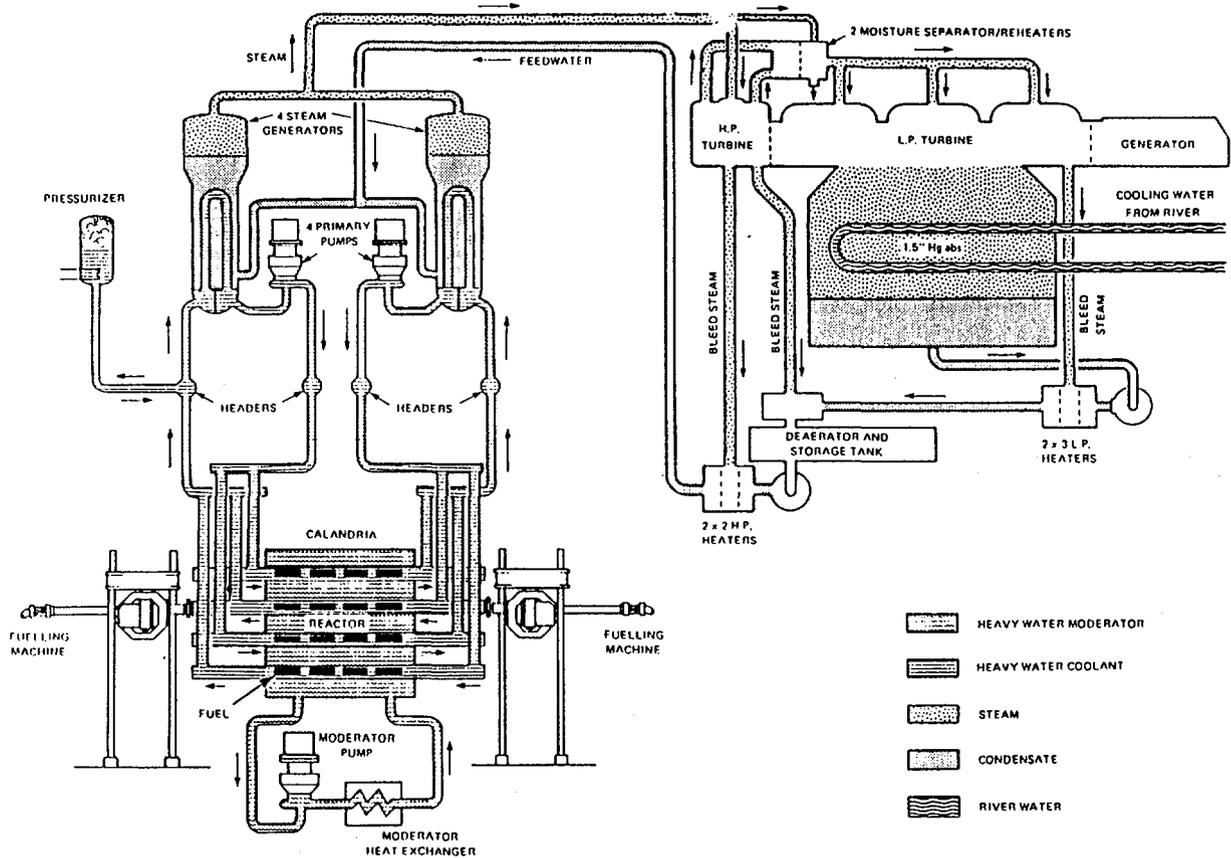


Figure 1 Schematic of CANDU Nuclear Power Plant

CANDU TECHNOLOGY

CANDU stands for Canada Deutrium Uranium. Figure 1 shows a simplified schematic of the CANDU Nuclear Power Plant.

The key characteristics of CANDU nuclear power system are :

- CANDU is a pressurized heavy water reactor (HWR).
- Heavy water is used for both the moderator and primary coolant resulting in high neutron economy
- The high neutron economy that permits the use of natural uranium fuel.

- The reactor is essentially a large tank (the Calandria), which contains the separate moderator at low pressure and low temperature, penetrated by a large number of pressure tubes that form part of the high pressure heat transfer system and contain the fuel.

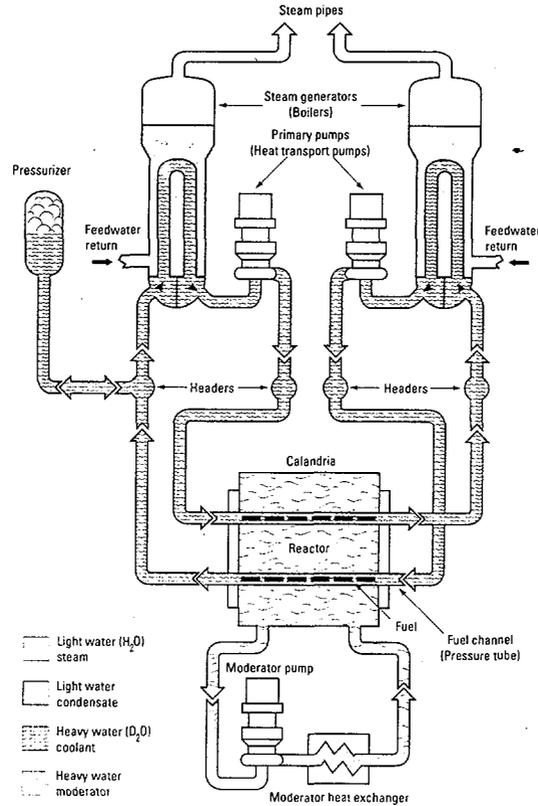


Figure 2 Schematic of CANDU Nuclear Steam Supply System

Figure 2 shows the CANDU NSSS schematic. Shown in this figure are, the separate moderator system with its heat exchangers and pumps, the primary coolant system with pumps and steam generators, the Calandria tank, and the fuel channels containing the natural uranium fuel bundles.

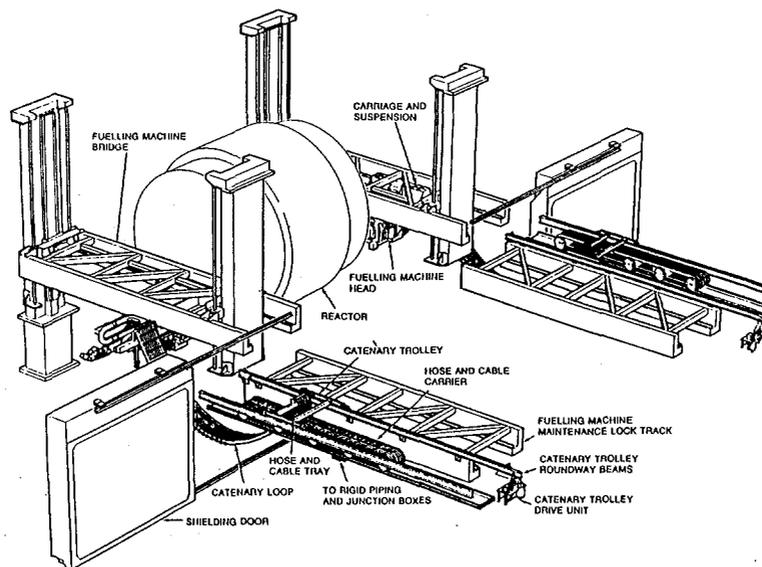


Figure 3 Schematic of the on-Power Refuelling

The reactor is refuelled on-power by two fuelling machines located at each end of the reactor (Figure 3). The fuelling machines are supported on a moving support structure, are remotely controlled by computers and access the entire face of the reactor. They load new fuel, remove spent fuel and shuffle fuel bundles to attain maximum burn-up. With on power refuelling, no outage is required to refuel the reactor. Overall reactivity of the reactor core is closely managed by the fuel management for easy control and to avoid excess reactivity at all times.

Some additional features unique to the CANDU are :

- Separation and independence of operation of process and power production systems from the safety systems.
- Two independent shutdown systems with different design concepts to ensure that no generic, common faults of the two systems are possible.
- Reactivity devices are located in low pressure and low temperature environment within calandria. This avoids any possibility of ejection from the core by the high pressure systems.

CANDU LICENSING AND SAFETY

The basic approach adopted by the regulatory bodies of CANDU client countries has been to accept the Canadian Licensing criteria and documentation, equivalent to those submitted for a reference plant in Canada.

The Canadian regulator, the Atomic Energy Control Board (AECB), generally plays a role in the transfer of expertise to international regulatory bodies by providing, among other things :

- licensing training courses
- attachment of personnel
- regular exchange meetings

In fact, during the previous round of Akkuyu negotiations in the mid 1980's, there was extensive contact and exchange programs between the AECB and TAEK. The result of his approach is that there are now licensed CANDU's in, Argentina, Korea, Romania, India and Pakistan.

In addition; there are presently on-going licensing activities in :

- Japan; joint studies with the Electric Power Development Corporation
- U.S.A.; pre-application review and design certification of CANDU with the USNRC (to 10 CFR 52)

LICENSING APPROACH

The Canadian Licensing Requirements are stated as regulations (R series) and consultative (C series) documents. The consultative documents are issued for trial use and public input prior to adoption as regulation documents. In the licensing process responsibility for meeting the requirements is on the designer. Regulators perform an auditing role to ensure compliance with the regulations.

The Canadian licensing process is not a prescriptive approach and allows innovation by the designer to improve the plant safety and the performance.

SAFETY

The Principle of defense in depth is the cornerstone of CANDU safety philosophy. This means

that :

- stations are designed, built and operated to the highest quality standards.
- failures of all important items to the safety of the plant are anticipated.
- normal process systems have the capability to control the events to prevent harm to the public.
- finally, multiple containment is provided to prevent the release of radioactive fission products to the environment

In addition important systems are grouped so that they are separated, both functionally and physically, to ensure each system can perform its function without reliance on other systems.

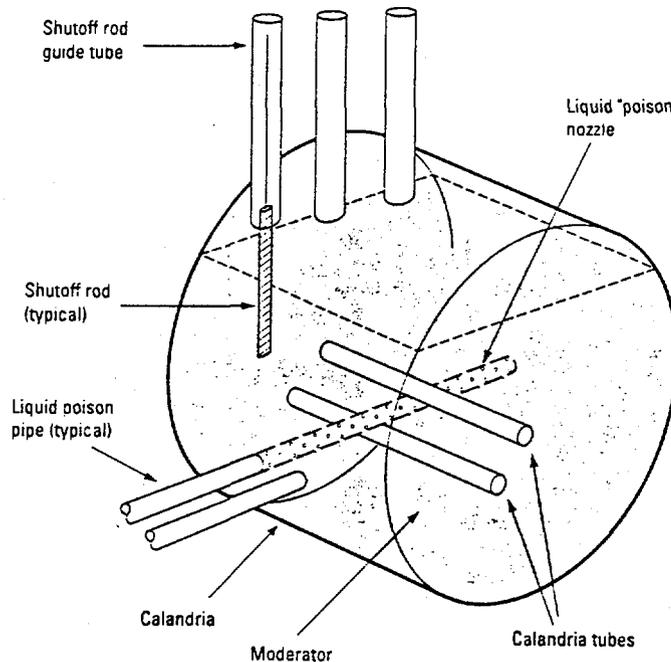


Figure 4 Schematic of the Reactor Shutdown Systems No.1 and No.2

A very unique feature of the CANDU, is the existence of two independent reactor-shutdown systems. These systems, shown schematically in Figure 4 are physically and functionally separate.

SDS 1 consists of shut off rods that fall under gravity. SDS 2 consists of liquid poison injection with gadolinium nitrate by high pressure stored helium.

In addition, the special safety systems consist of an emergency-core-cooling system and the containment system. These are designed to limit the consequences to the core and spread of radioactivity should any process system failure occur.

Mitigation of severe accidents by unique CANDU features provides additional safety to the CANDU, This is the large amount of low temperature heavy water in the calandria vessel, which in turn is surrounded by a large shield tank containing light calandria vessel, which in turn is surrounded by a large shield tank containing light water. This large volume of water is available as heat sinks for the more extreme severe accidents scenarios which can be postulated.

CANDU ADVANCEMENTS

CANDU advancements are based on Evolutionary Plant Improvements. They consist of system performance improvements, Design Technology Improvements and research and development in support of advanced nuclear power.

The Reference Plant CANDU 6 design is being carried out using the following advanced technologies :

- Computerized Integrated Design and Drafting system.
- Integrated Analytical Environment - AECL is developing software for an integrated analytical environment so that multiple handling of the design data is eliminated thereby reducing errors.
- Enhancement of Design Tools for safety Software development- The computer safety software used in a CANDU plant is produced with the help of advanced tools and aids to ensure exact compliance with specifications and the production of high quality and reliable software.
- Advances are being made in computerized Integration of Design Outputs and Construction Input Data which can provide an integrated data base for plant maintenance.

Given the good performance of CANDU plants, it is important that this CANDU operating experience be incorporated into new and repeat designs. This is being done in the CANDU 6 plants now under construction which also incorporate evolving safety requirements and improvements in component technology and plant systems.

All these advancements and improvements are backed by an extensive research and development. AECL as an integrated company not only builds NPP but also undertakes a comprehensive research and development program.

CANDU FUEL CYCLES

A significant feature of CANDU design is its flexibility to adapt to different fuel cycles including :

- Natural Uranium
- Advanced Fuel Cycles
- Thorium Fuel Cycles

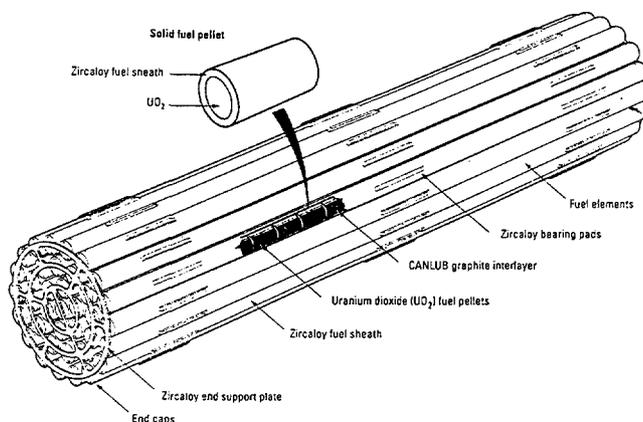


Figure 5 CANDU 6 Fuel Bundle (37 element)

NATURAL URANIUM

CANDU reactor has been designed for the use of natural Uranium. Natural Uranium fuel eliminates the need for enrichment facilities. Figure 5 shows the CANDU fuel bundle which is 0.5 m long, 10 cm in diameter and 23 kg in weight. Ease of CANDU natural uranium fuel fabrication has enabled all CANDU owners to obtain fuel from their own country.

ADVANCED FUEL CYCLE PROGRAMS

AECL has conducted research and development programs on Advanced Fuel Cycles over many years and there are several joint development programs underway with international partners. These include :

- Japan - Evaluating use of Slightly Enriched Uranium (SEU) with enrichments from 0.9% to 3%.
- France - Evaluating the fabrication of CANDU fuel using Recovered Uranium.
- Korea - joint studies to evaluate the use of spent PWR fuel, refabricated into CANDU fuel.
- Netherlands - evaluating the use of SEU.

In the area of spent Fuel Detoxification there are some exciting possibilities being studied on the use of CANDU to burn higher actinides.

An interesting alternative for reducing the radiotoxicity of spent fuel is to use the once through thorium cycle in CANDU. This is particularly attractive since CANDU has low fissile requirements. This cycle reduces the contribution of actinides to radiotoxicity by two orders of magnitudes.

The recent International Conference on Future Nuclear Systems (Global 93) has recognized CANDU as an existing technology that could be utilized to assist in management of nuclear wastes. Planning of entire nuclear cycles is seen as necessary to launch the second generation of the nuclear era.

THORIUM

AECL has carried out research on thorium fuel over the past 30 years. Research reports are available which describe these developments. Thorium can be mixed with fissile material such as Natural Uranium, Slightly Enriched Uranium, or mixed oxides of uranium and plutonium.

There are basically two options to be considered; direct use and spent fuel reprocessing.

The first option has the following steps;

- Thorium is converted to Protactinium 233 in the bundles in the low flux (outer channel) regions of the core of the CANDU reactors.
- The bundles are then placed in interim storage in the spent fuel bay (cooling for about 3 months) to allow decay of Protactinium 233 to U233.
- The bundles are then re-inserted into the central, high flux regions of the core to deplete the U233.

This option could be implemented presently.

The second option includes the following steps :

- Thorium is converted to Proactinium 233 in the bundles in the low flux (outer channel) regions of the core of the CANDU reactors.
- The bundles are then placed in interim storage in the spent fuel bay (cooling for about 3 months) to allow decay of Proactinium 233 to U233.
- Chemical separation of U233
- Fabrication of Th232 / U233 fuel
- Refuelling with Th232 / U233 fuel

This option has potential of achieving a self-sufficient equilibrium thorium cycle in CANDU reactors.

SUMMARY OF CANDU ADVANTAGES

In summary, as Turkey once again considers proposals for the Akkuyu site, the CANDU 6 represents a proven and credible product.

There are four CANDU 6 units presently under construction and secheduled to come into service between 1995 and 1999. This provides for a proven option that is based on a demonstrated schedule, competitive economics, modern technology, latest regulations and overall benefits of replication.

As recently as 1992, Candu 6 has proven to be competitive economically with latest alternatives to CANDU.

CANDU 6 has an up to date licensability in user countries meeting all known current requirements.

The presently active design and construction program of CANDU 6, offers an experienced team for all phases of Project from design to supply, construction commissioning and operation. This team is ready and available now.

AECL CANDU and CANDU owners offer Turkey the opportunity to acquire total technology for nuclear self reliance in the shortest time.

Once again AECL and CANADA stand ready to meet Turkey's needs now.