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The importance of nuclear energy for the expansion of world's energy demand

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Abstract. This paper describes nuclear energy technologies for the solution of long term energy problem with better reliability. A short overview about nuclear energy applications are explained with a basic analysis of energy. Furthermore, industrial application, space application of nuclear systems and ship propulsion in nuclear energy application are demonstrated in more detail. This report also includes some examples of the experienced nuclear power plant to identify energy production. The general purpose of the article is to understand how efficiently nuclear systems generates energy, and solve the world`s increasing energy demand in our century.

Keywords: nuclear energy technologies; energy planning; industrial application; space application; ship propulsion in nuclear energy

1. Introduction

The demand for energy has significantly increased due to the astonishing development in technological tools recently. As a natural consequence of this situation, some harmful resources such as fossil fuels have been used for providing energy without considering their damage in the environment or people's lives. It was really possible to generate quite enough energy from the non-renewable energy sources compared to the renewable energy sources. However, high percentage of usage of non-renewable energy sources caused some hazardous environmental and health related issues which people are still facing today. For instance, some include greenhouse gas emission, global warming and climate change. Because of the limitation of the non-renewable sources and limited energy potential of some renewable sources, nuclear energy was considered to be exact solution for energy problems (Sims *et al.* 2003). The extreme needs for energy and capability of generating high and clean energy from the nuclear energy system led to a rapid increase in nuclear energy technology mainly for electricity generation (Hammond 1996). Even though there was some concern about the probability of damage to be likely caused by nuclear systems, technological developments and the improvements in nuclear technology in terms of cost, environment and socioeconomic consideration increased the reliability of the nuclear energy systems (Lee *et al.* 2007).

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Table 1 Distribution of the potential usage area of the nuclear in industry with average temperature (Majumdar 2002)

Industrial process	Approximate Temperature Range (Centigrade)	references
Home and building heating	100-130	(Majumdar 2002)
Desalination	100-130	(Majumdar 2002)
Vinyl Chloride production	100-200	(Majumdar 2002)
Urea synthesis	180-280	(Majumdar 2002)
Process Steam	200-400	(Majumdar 2002)
Paper and pulp production	200-400	(Majumdar 2002)
Oil refining	200-600	(Majumdar 2002)
Oil shale and oil sand processing	300-600	(Majumdar 2002)
Crude oil desulphurisation	300-500	(Majumdar 2002)
Petroleum refineries	450-550	(Majumdar 2002)
Production of synthetic gas and Hydrogen from natural gas or naphtha	400-800	(Majumdar 2002)
Steel making via direct reduction	500-1000	(Majumdar 2002)
Iron industry	600-1600	(Majumdar 2002)
Production of styrene from ethyl-benzene	600-800	(Majumdar 2002)
Production of ethylene from naphtha or ethane	700-900	(Majumdar 2002)
Hydrogen production by thermo-chemical reaction	600-1000	(Majumdar 2002)
Coal processing	400-1000	(Majumdar 2002)
Coal gasification	800-1000	(Majumdar 2002)

The continuous increase in the nuclear technology proved that the nuclear system was a perfect solution for long term energy problem with better reliability, safety and high energy output ability (Omoto 2005). Depending on this development in nuclear technology, it was used for some non-electricity applications such as space, ship propulsion and in industry. The purpose of this essay is to technically explore the probability and feasibility of the nuclear energy systems in such non-electricity applications.

2. Industrial application

Nuclear energy is considered to be a preferable application to generate energy such as electricity or heat energy with the deployment of developed reactor which consume lower uranium (Massara 2009). Due to the high probability of generating a great amount of energy from the nuclear reaction, there are several applications which provide energy from nuclear base system in different ways as well as nuclear non electricity application, which will likely be the perfect solution for the energy problem in the future with such applications (Omoto 2005). Industrial (desalination), space, medicine and ship propulsion (non-electric applications) are thought as the most important applications in order to use nuclear technology apart from the use of it for electricity generation (Majumdar 2002). It is clear to observe that there is a strong increase in the

Table 2 Example of the experienced nuclear power plant for distillation (Majumdar 2002)

Plant Name	Reactor Type	Gross Power (MWe)	Desalination Process	Water Capacity M3/d
Ikata-1,2 (Japan)	PWR	1132	MSF	200
Ikata-3 (Japan)	PWR	890	RO	2000
Ohi-1,2 (Japan)	PWR	2350	MSF	3900
Ohi-3,4 (Japan)	PWR	2360	RO	2600
Genkai-4 (Japan)	PWR	1180	RO	1000
Genkai-3,4 (Japan)	PWR	2360	MED	1000
Takahama-3,4 (Japan)	PWR	1740	MED	1000
Kashiwazaki (Japan) BWR	PWR	1100	MSF	1000
KANUPP (Pakistan)	PHWR	137	RO	454
BN-350 (Kazakhstan)	LMR	150	MSF&MED	80000

use of those kinds of applications (Majumdar 2002). The increase might be owing to the astonishing demand for energy either in electric application or non-electric applications. Even though there is a significant interest and investment in generating energy from the renewable energy source; fossil fuels are still the main energy source with the percentage around 78 % (Boyle *et al.* 2003). The high usage of fossil fuels resulted in dangerous environmental hazards that people are facing today. Therefore, it is considerably important to provide wider usage area for the nuclear energy in order to generate more energy for replacing the fossil fuels. One of the important non electric applications of the nuclear energy is the usage of the nuclear sources for industrial purposes. There are many different types of industrial usage of nuclear, as presented in Table 1.

There are various applications to use nuclear energy in industrial areas (Table 1), therefore it is expected that different types of rector were used to provide higher efficiencies by applying the most convenient application (Majumdar 2002). Each reactor has different range of inlet and outland heat and steam (IAEA 1999). Desalination application of the industrial usage of nuclear energy can be considered a major application. It is obviously known that water is a vital resource for all creatures in order to continue their lives. In addition, people are required to have drinking water which is needed to be desalinated. Because, there is a significant concern about having lack of drinking water in the world due to the lack of energy to desalinate salt water (94% of the total water in the world) (Majumdar 2002). Nuclear energy can be a perfect option to deal with this problem as mentioned above due to the possibility of generating needed amount and type of energy. Regarding this point, some investigations have been done from 1960 to today about using nuclear in the desalination of the salt water (Majumdar 2002). In this respect, Table 2 illustrates some examples of experiences about desalination.

The circuit for a simple desalination nuclear plant was shown in Fig. 1, and its cost changes from about \$0.50 to around \$2.0 perM^3 of distilled drinking water (IAEA 2005).

There are considerable numbers of nuclear reactor designs for water desalination due to the high attraction and importance of desalination application as an example of industrial usage of nuclear energy and availability of using nuclear technology in that application. For instance, The French PWR-900 is one of the preferable reactors which is a quite famous reactor with relatively lower cost and possibility of construction of series units. On the other hand, The Westinghouse AP-600 has also substantial importance that provides controllable power rate, simple safety units and availability of configuration (Nisan *et al.* 2003). In the desalination process, the water vapour

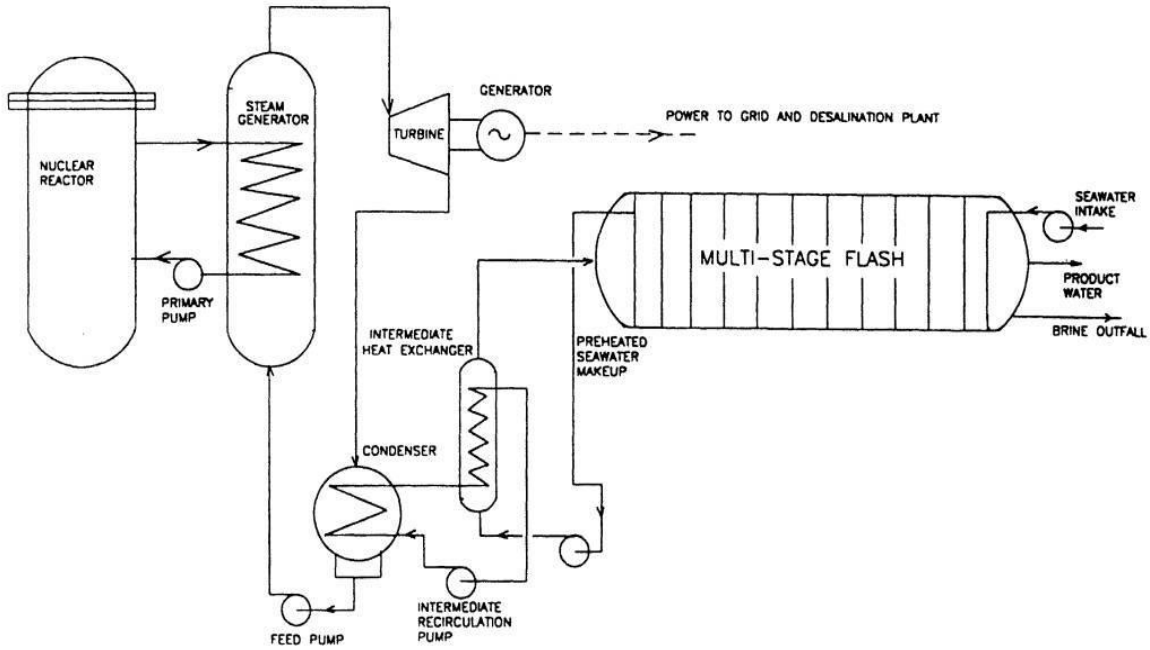

Fig. 1 Schematic illustration of a simple desalination nuclear reactor circuit (Majumdar 2002)

is generated by heating the salt water until the needed temperature which is mainly supplied by low pressure water-logged steam (Khan 1986). There are two important desalination methods: Multiple effect distillation (MED) and Reverse osmosis (RO) desalinations (Nisan *et al.* 2003), about which some technical information has been provided above in Table 2.

It is clearly understood that desalination plays a vital role in people's lives in order to obtain drinking water due to the increasing demand for clean water in the world. In this concept, nuclear energy is strongly needed to provide the necessary power such as heat or steam for this application.

3. Space application of the nuclear systems

Using nuclear energy as an energy supplier system in space application is a considerably significant investigation that is improved every year. This might be due to the availability of obtaining comparatively higher energy from the nuclear energy system as heat or directly as power. Knight (2000) also agrees with the point that it is obviously possible to have higher performance engine by applying nuclear energy system. There have been many attempts from around 1950s to today in order to investigate the feasibility of using nuclear propulsion system in the space products technology such as in space craft application (Klein 2004). Especially for developed countries, the space application of nuclear energy was an attractive invention. It is because high propulsion energy is required for space product, and it is possible to obtain needed energy from the nuclear system. Although the generated power of the nuclear reactor depends on the conversion of heat to electricity, nuclear power technology was considered to be an acceptable

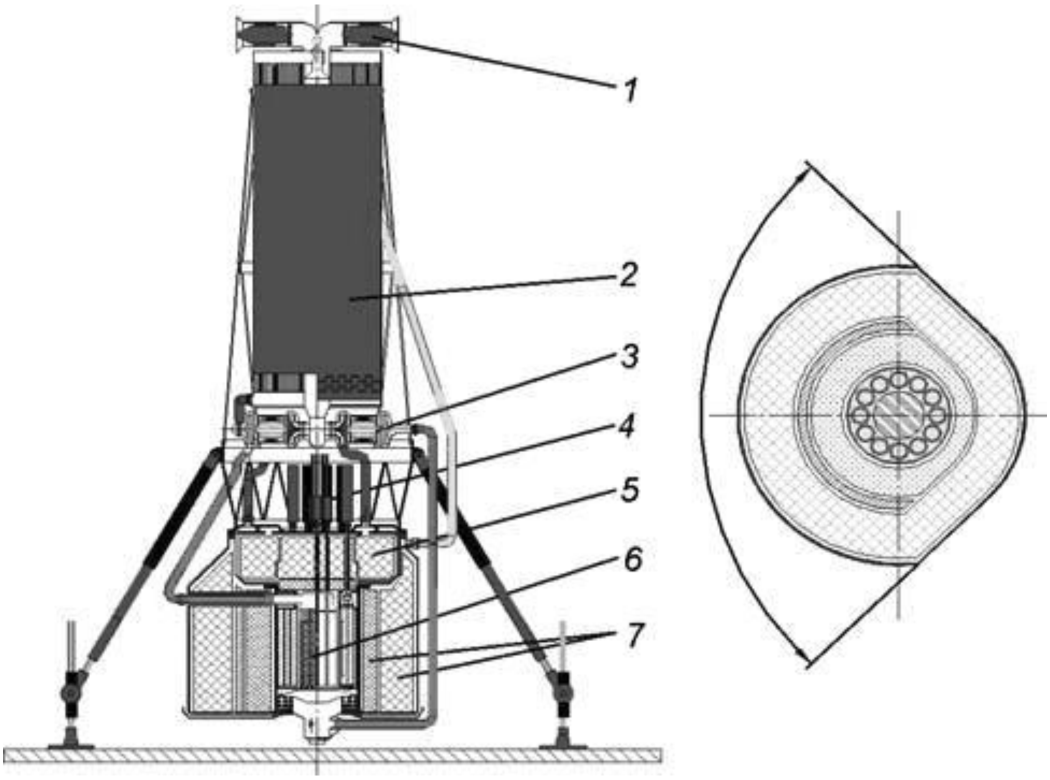

Fig. 2 Schematics of the nuclear reactor motor (USA and USSR) adapted from Gabaraev (2007)

Table 3 Differences between the USA and USSR nuclear powered space reactor (Gabaraev 2007)

Properties	USSR	USA	References
Principles for developing NRM	Element-by-element	Integrated	(Gabaraev 2007)
Average core heat density	15	2.3	(Gabaraev 2007)
Maximum core heat density	33	5.1	(Gabaraev 2007)
Specific thrust impulse, sec	~940	~850	(Gabaraev 2007)
Service life at maximum working-body temperature, sec	4000	50	(Gabaraev 2007)

solution to meet high power needs (Gordeev *et al.* 2012). The USA and USSR were considered to be prior in the investigation of the nuclear use in space area. They conducted a work on the design of the nuclear powered space rocket engine after 1950s (Gabaraev 2007).

In comparison to the USA, the core heat, working part of the reactor and the total needed time to complete the operation is higher in USSR design (Gabaraev 2007). Some technical properties of the reactor were given in Table 3 for both the USA and USSR.

With the increasing use of the technology, nuclear power skill in space application has also been raised. Some institutes were established in order to improve the space application such as research and design institutes and nuclear space institutes (Gabaraev 2007). The generation of the high power from a relatively lesser scope reactor was probably the main concern in this technology. Additionally, having advance safety system and stability of the structure of the reactor

Table 4 Timetable for NERVA test with power (Klein 2007)

Date	Test article	NRDS Facility	Maximum power (MW)	Time at Maximum power
1 July 1959	Kiwi A	A	70	5 min.
10 Oct 1960	Kiwi A	A	85	6 min.
30 Nov 1962 Kiwi	Kiwi B4A	A	500	Several seconds
15 Oct 1964	NRX A2	A	performance	mapping
23 June 1966	NRX A5	A	1050	14.5 min.
18 July 1968	Phoebus 2A	C	3430	30 min.
11 June 1969	XE Prime	ETS 1	1140	3.5 min.

Table 5 General technical properties of a developed space reactor adapted by Cammi *et al.* (2009)

CONSIDERATION	VALUE
Net power	100 kWe
Type	PWR
Design Fuel	Integrated layout/93% enriched uranium
Composition	45% U-55% $ZrH_{1.7}$
Moderator and coolant	H_2O
Water/solid ratio	0.20
Fuel rod diameter	15.23 mm
Cladding OD	17.82 mm
Cladding thickness	1.12 mm
Fuel cluster geometry	7 rod hexagonal in wrapper
Wrapper mat and thick.	AISI 316L; 0.3 mm
Lifetime	4000 days
Reflector	80 mm BeO+40mm H_2O
Core geometry	Hexagonal
Inlet temperature	335 C^0
Outlet temperature	345 C^0
Pressure	15.5 MPa
Primary side mass flow rate	10.24 Kg/s
Secondary side mass flow rate	0.347 Kg/s
Coolant area	0.0125 m^2
Coolant speed	1.133 m/s
Secondary fluid	H_2O
Max. Temperature	325 C^0
Min. temperature	165 C^0
Pressure	4.8 MPa
Thermodynamic cycle	Rankine
Net efficiency	12.5 %
Thermal power	800 kW

were considered to be another crucial condition in high developed nuclear base space products (Gordeev *et al.* 2012).

NASA, which is the most widely known organization in order to study space, and AEC (atomic energy commission), also intended to obtain information about the feasibility of the nuclear energy in space application (Klein 2007). The NERVA program was the first attempt to use nuclear technology to design a thermal reactor for space implementation by Los Alamos National Laboratory (Klein 2007). NASA and AEC focused on improving the NERVA system in terms of the safety and reliability by configuring some technical equipment such as control system nozzle. With the increasing use of the nuclear technology, many tests have been done in order to improve the capability of the NERVA reactor (Table 4) (Klein 2007).

Many scientists have reached a consensus that by using nuclear thermal reactor technology for space explorations, the human mission could be exchanged with the machine. Furthermore, the missions will be done with a lower power and lower required technical equipment by the increase in nuclear in space science (Borowski 1993). The availability of the nuclear energy usage in the space application will give chance to do more experiments about the space investigation. In addition to the technical features of the mentioned above, Cammi *et al.* (2009) provided data about a relatively more developed nuclear space reactor (Table 5).

4. Ship propulsion

Nuclear energy Application in ship science is another increasing attraction in order to increase needed power easily from a nuclear reactor. With the rapid growing of the ship technology, there are many kinds of ships were designed with significantly high mass which requires high power. On the other hand, due to the large size of the recently developed ships, the fuel consumption of the ships also increased with a considerable amount of greenhouse gas emissions (Garcia *et al.* 2012). All this notable reasons proved that there was a strong need for environmentally friendly and powerful energy supplier system. Nuclear energy as a renewable energy sources has a

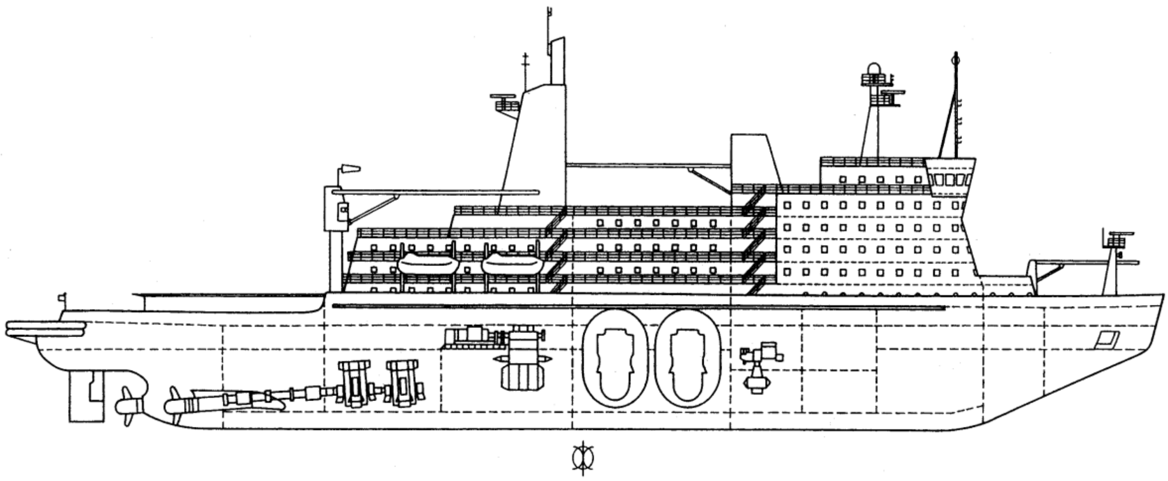

Fig. 3 Schematic of the place of the MRX put in the middle part of the icebreaker ship adapted from Kusunoki (2000)

Table 6 Some key properties of the MRX ship nuclear reactor (Kusunoki 2000).

Important parameter of the MRX reactor	Values
Reactor power	100 MWt
Reactor type	Integral type
Reactor coolant Operating pressure	12 MPa
Inlet: outlet temp.	282.5:297.5℃
Flow rate	4500 t h_1
Core: Fuel Equivalent dia.	1.49 m
Effective height	1.40 m
Av. linear heat flux	7.9 kW m_1
Fuel type Zry-clad	UO2 fuel
U-235 enrichment	4.3%
Fuel inventory	6.3 ton
Fuel Av. burn-up	22.6 GWd
No. of fuel assembly	19
Fuel rod outer dia.	9.5 mm
Control rod dri6e mechanism Type and No. of CRDM	In-vessel type and13
Main coolant pump Type/ Rated power /No. of Pumps	Horizontal axial flow canned motor type/200 kW/2
Steam generator Type /Tube material /Tube outer: inner dia.	Once-through helical coil type /Incoloy 800/19:14.8 mm
Steam temp: press /flow rate	289℃:4.0 MPa/168 ton/ h
Heat transfer area	754 m^2
Reactor Vessel Inner diameter: height	3.7:9.7 m
Containment Inner diameter: height	7.3:13 m

relatively better reliability and high power capability with different types of applications (Kusunoki 2000). It was also claimed (Kusunoki 2000) that there are great amount of experiment carried out to design the most efficient reactor for ship propulsion. In this respect, MRX (Marine Reactor X) (Table 6) was claimed as the most suitable reactor to meet the needs for ship propulsion technology in terms of safety, power output, weight, compact structure and reactor efficiency (Kusunoki 2000) Fig. 3.

Krishna (2011) mentioned about the requirement or expectation for nuclear system in the ship science that there is a significant increase in the ship application of the nuclear energy. Lower cost, lower emission and easy installation of the reactor were considered to be the main requirement for nuclear technology in the ship application. Having a continuous recirculation of the water was a crucial condition for using nuclear in ship propulsion, the key components of which were initially circulated with water (Krishna 2011). Naval ship is a perfect example for proving the feasibility of the nuclear system in ship propulsion where the performance of the naval ship was greatly increased in terms of safety maintenance, cost and needed power output (Krishna 2011).

5. Conclusions

Nuclear energy technology as a renewable energy source is a strong candidate to be a solution for the world's increasing energy demand in our century. Due to its capability to provide relatively high energy output rate, nuclear technology is an attractive area for any energy based systems.

Nuclear technology was mainly applied for generating electricity for electricity required products or public concern. However, there is a great possibility to use nuclear technology in non-electricity applications such as space and ship propulsion or industrial consideration. Nuclear energy systems have been developed to be consonant with such application. The size and types of the reactors were also chosen according to the user purpose of the system. Some applications such as ship propulsion required high power rate due to the high mass of the structure. Therefore a system is required which has the ability to provide high power at the needed time. Nuclear energy systems have the ability to provide enough power to meet high energy demand for further applications.

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