Desalination and Other Non-electric Applications of Nuclear Energy

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Abstract

As the standard of living increases globally, the need for fresh water and industrial products is also increasing; they require energy for production and hence, the demand for energy – both electric and non-electric, is also increasing. Nuclear energy provides now only about 7% of global energy use; fossil fuels which degrade the environment provide the rest. Nuclear energy has the potential to provide an abundance of greenhouse-gas-free energy for mankind. Currently, nuclear energy is mainly used for electricity production. This paper discusses non-electric applications of nuclear energy, summarizing the global status and enumerating the areas where it could be used.

1. INTRODUCTION

Some of the first civilian reactors in the world were used to supply heat, e.g., Calder Hall in UK (1956) and Agesta in Sweden (1963). Calder Hall provided electricity to the grid and heat to a fuel reprocessing plant, and Agesta provided hot water for district heating of a suburb of Stockholm. The first nuclear power station in Russia (1954) was also a multi-purpose facility providing electricity and heat to the closed city of Obninsk in Kaluja region, near Moscow. Currently less than 1% of the heat generated in nuclear reactors is used for non-electric applications[1]. Direct use of heat energy is more desirable from an energy efficiency point of view and nuclear energy is an enormous source of greenhouse-gas-free energy. However, nuclear power has remained primarily a source for electricity generation. Presently about 30% of the world's primary energy is used for electricity production, and approximately 2/3 of this energy is thrown away as waste heat. Yet despite past and current use models, it is possible to optimise the use of nuclear heat for both electric and non-electric applications, thereby making more efficient use of nuclear energy. Experience in co-generation of nuclear electricity and heat has been gained in Bulgaria, Canada, China, Hungary, Kazakhstan, Russia, Slovakia and Ukraine[2]. This paper examines the scope of non-electric applications of nuclear energy[3] .

There are four areas where nuclear heat can be utilized: for desalination of salty and waste water, district heating of residence and commercial buildings in cold countries, industrial process heat supply, and fuel synthesis. Primary experience of non-electric applications of nuclear energy is in the first two categories. There are more than 150 reactor-years of operating experience with nuclear desalination, particularly in Japan and Kazakhstan. District heating systems from nuclear power plants have operated reliably in many countries, particularly in Eastern Europe. Fuel synthesis has evolved in recent years because nuclear energy can generate high temperature heat; this heat can be used for hydrogen production, coal gasification and production of other fuels. The heating requirements of different industrial processes vary. The temperature requirements for the principal applications are shown in Table I. They vary from low temperature applications for hot water to high temperature industrial processes.

TABLE I. TEMPERATURE NEEDS OF VARIOUS TYPES
OF INDUSTRIAL PROCESSES

Industrial Process	Approximate Temperature Range (Centigrade)
Home and building heating	100 – 170
Desalination	100 – 130
Vinyl Chloride production	100 – 200
Urea synthesis	180 – 280
Process Steam	200 – 400
Paper and pulp production	200 – 400
Oil refining	200 – 600
Oil shale and oil sand processing	300 – 600
Crude oil desulphurisation	300 – 500
Petroleum refineries	450 –550
Production of synthetic gas and Hydrogen from natural gas or naphtha	400 – 800
Steel making via direct reduction	500 – 1000
Iron industry	600 – 1600
Production of styrene from ethyl-benzene	600 – 800
Production of ethylene from naphtha or ethane	700 – 900
Hydrogen production by thermo-chemical reaction	600 – 1000
Coal processing	400 – 1000
Coal gasification	800 –1000

Various types of reactors are designed with different ranges of inlet and outlet coolant temperatures, and hence will be useful for different applications. Table II shows the range of coolant temperatures for different reactor types. A nuclear plant can provide steam or process heat from about 100 C for district heating or desalination to about 1000 C for very high temperature industrial applications. Table III shows the characteristic parameters of steam that could be produced by various reactor types[4]. Water reactors can provide steam in the range of 250 to 300 C at about 5 to 7 Mpa pressure, while liquid metal and gas cooled reactors can generate steam at higher temperature and pressure. LMFBRs can provide steam at approximately 500 C and gas cooled reactors at somewhat higher temperatures.

TABLE II. TEMPERATURE CAPABILITIES OF REACTOR TYPES

Reactor Type	Typical Primary Coolant Inlet & Outlet Temperatures (Centigrade)
Pressurized Water Reactor (PWR)	280 – 320
Water Reactor (BWR)	278 – 288
Heavy Water Reactor (HWR)	250 – 295
Liquid Metal-cooled Reactor (LMCR)	390 – 540
High Temperature Gas-cooled Reactor (HTGR)	500 – 950

TABLE III. TYPICAL STEAM PRODUCTION BY DIFFERENT REACTOR TYPES

Nuclear Power Plant	Steam Parameters	
	Pressure (Mpa)	Temperature (C)
PWR (U-tube SG)	6.5	280
PWR (Once-through SG)	6.9	312
BWR	5.5	270
PHWR	5.6	271
CANDU PHWR	4.7	260
Phenix LMFBR	16.3	510
THTR-300	18.1	530
Fort St.Vrain HTGR	17.3	541

2. DESALINATION

Water is essential for living but over a billion people, approximately 20% of the world's population, lack safe drinking water, and three billion lack access to adequate sanitation[5] for lack of water. Unfortunately, 94% of the world's water is salt water and only 6% is fresh[6], and less than 1% of the fresh water is easily accessible (27% being in the glaciers and 72% underground). As the standard of living increases all over the globe, the demand for both energy and water is also increasing. In this regard, the development and use of water desalination technologies[7] are helping tremendously. Desalination of water requires energy but, as shown in Table I, it can be done at relatively low temperatures. Waste heat from power plants is sufficient for this purpose. Nuclear power can play a significant role, particularly in a dual capacity, by providing water in addition to greenhouse-gas-free energy. Many years of successful operation have proved the technical feasibility and reliability of nuclear plants for producing fresh water[†].

Desalination technologies have evolved over the past 50 years to large-scale commercial processes. The major commercially available processes are of two kinds: (a) thermal processes, where heat is used to vaporize and distill fresh water from saline water; these are multi-stage flash distillation (MSF), multiple-effect distillation (MED), and vapor compression (VC), and (b) membrane processes where suitable membranes are used for the separation of salts such as the mechanism of reverse osmosis (RO). There are also other minor processes such as freezing and solar evaporation. Globally about 26 million m^3/d of fresh water is produced by desalination (including both brackish and seawater plants). The maximum is produced in Saudi Arabia, about 21%. The U.S. produces approximately 17%, 80% of which is achieved by membrane processes.

The possibility of using nuclear energy for desalination of seawater was realized as early as the 1960s. Experience with nuclear desalination now exceeds 150 reactor-years. Table IV gives a list of the nuclear plants, which have been used for desalination of water; it also provides information about the reactor types, desalination technologies employed and the fresh water capacity of the plant[8]. The Kazakhstan nuclear plant was shut down in 1999 and was the only power reactor in the world supplying heat for industrial-scale desalination[9]. It produced 80,000 m^3/d of potable water for municipal use. The Diablo Canyon Nuclear Power Plant in the U.S. also produces 4500 m^3/d of fresh water from the sea for in-plant use; they use RO membrane technology[10]. Table V gives details of operating experience of LWRs in Japan, a PHWR in Pakistan, and the LMR in Kazakhstan. It should particularly be noted that there was no incidence of radioactive contamination of the water produced.

[†] Nuclear desalination can be described as production of potable water from seawater or brackish water in a facility in which a nuclear reactor is used as the source of energy for the desalination process.

TABLE IV. EXPERIENCE IN NUCLEAR DESALINATION PLANTS

Plant Name	Reactor Type	Gross Power (MWe)	Desalination Process	Water Capacity M^3/d
Ikata-1,2 (Japan)	PWR	2x566	MSF	200
Ikata-3 (Japan)	PWR	890	RO	2000
Ohi-1,2 (Japan)	PWR	2x1175	MSF	3900
Ohi-3,4 (Japan)	PWR	2x1180	RO	2600
Genkai-4 (Japan)	PWR	1180	RO	1000
Genkai-3,4 (Japan)	PWR	2x1180	MED	1000
Takahama-3,4 (Japan)	PWR	2x870	MED	1000
Kashiwazaki (Japan)	BWR	1100	MSF	1000
KANUPP (Pakistan)	PHWR	137	RO	454
BN-350 (Kazakhstan)	LMR	150 (till 1999)	MSF & MED	80000

TABLE V. NUCLEAR DESALINATION OPERATING EXPERIENCE

	Japan	Kazakhstan	Pakistan
Starting Year	1978	1973	2000
Reactor Type	LWR	LMR	PHWR
Capacity (m^3/day)	100-3900	80,000 (design 120,000)	454
Average salinity of intake water (mg/l)	35,000	13,500	24,000
Average temperature (C)	17	2-24	
Radioactive leak	None	None	None
Water Production during NPP shutdown	Halted, no need for water. No backup source	Continued by a fossil boiler	None
Failures and types	Nothing reported	Corrosion and erosion of tubes and pump blades	Not reported
Availability	~50% Not operated once the storage tank is filled.	85%	
Product water use	In plant use for steam cycle	In plant & municipal use, including drinking water	In plant use

An example of how nuclear heat is used for desalination is shown in figure 1. In this example steam is produced in a secondary loop for generation of electricity and then another tertiary loop is used to heat the seawater for desalination. The salt water is in the 4th loop. This makes the production of fresh water far removed from the radioactive isotopes of the first, primary loop.

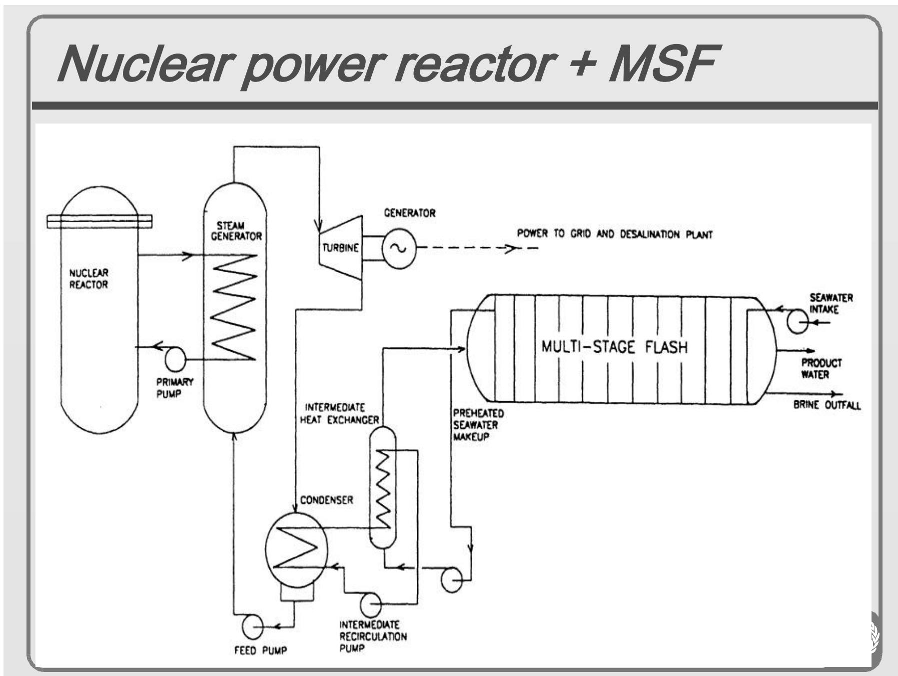

FIG. 1 Schematic presentation of nuclear desalination circuits

Economic studies performed at the IAEA indicate that nuclear energy can be competitive for desalination compared with fossil-fuelled energy sources[11]. The desalination costs range from \$0.40 to \$1.90 per m^3 of fresh water produced. It was generally found that (a) MSF processes cost higher than RO and MED processes, (b) RO and MED processes costs are in general comparable, (c) RO is economically more favourable for less stringent drinking standards, and (d) desalination costs are higher for smaller reactors.

Various research and construction project studies are being performed in several countries for nuclear desalination. Currently major activities are taking place in India, Pakistan, Russia, and China; Canada, Republic of Korea and France are also involved in nuclear desalination research. India[12] is constructing a 6300 m^3/d combined MSF-RO nuclear desalination demonstration plant connected to two 170 MWe PHWR units at Kalpakkam. Installation of the RO section has been completed and the MSF section is expected to be done in 2003. Pakistan has initiated a feasibility study for coupling a 4500m^3/d desalination plant with the 137 MWe PHWR KANUPP. Russia has investigated various coupling schemes for 35 MWe KLT-40, 55 MWt RUTA, and 70 MWe NIKA reactors. Russia and Canada are working on a floating nuclear desalination plant with the KLT-40 reactor and an optimised Canadian desalination system involving reverse osmosis. The construction of the KLT-40 on a barge is expected to be completed in 2006. China is investigating a nuclear desalination project in Shandong peninsula with a 200 MWt nuclear heating reactor (NHR-200). Their plan is couple it to an MED process to produce 160,000 m^3/d of potable water. The study was finalized in 2001, and Tsinghua University is setting up a test system to verify the design performance of the MED process. Candesal Technologies in Canada is developing a unique approach to the design and operation of RO system to improve energy efficiency and reduce the life cycle cost of potable water. The Republic of Korea (ROK) is developing an integrated desalination plant with the SMART reactor for dual purpose application. They aim to provide 90 MWe and 40,000 m^3/d of fresh water. A 65 MWt pilot version of the SMART reactor is expected to be built in the ROK by 2008. ROK and Indonesia are also investigating the feasibility of nuclear desalination in Madura Island, Indonesia. France is working with Tunisia for a site-specific desalination study for La Skhira in Tunisia.

Nuclear desalination is thus a matured technology and can be installed in many nuclear plants to provide fresh water to solve regional water shortage problems. The desalination capacities of the world have been doubling each decade and hence there is a tremendous potential for nuclear desalination. Efforts are now primarily directed towards reducing production cost of desalinated water through innovations and technological enhancements.

3. DISTRICT HEATING

District heating is residential and commercial building heating. District heating systems use hot water or steam in the temperature range of 70 – 150 C with steam-water and water-water heat exchangers as needed. Usually steam is extracted from low pressure turbines in the nuclear power plant to provide the base heating load and steam from the high pressure turbine is used for the peak heat demand. Development of a heat distribution system is required but, due to heat losses in the heat distribution system, the source must be nearby, usually within a few kilometres at most. The longest known delivery distance is 24 km in Slovakia. Also, the demand for heat fluctuates with the season, being very high in cold winters and low in summer, and the source must be able to accommodate this fluctuation.

District heating has been used in some countries for decades. District heating networks exist in Bulgaria, Czech Republic, Hungary, Slovakia, Belarus, Russia and Ukraine. Denmark, Finland, Sweden, and Switzerland also have developed heating networks. The power capacity of heat networks is estimated to be about 600 – 1200

MWt in large cities and 10 –50 MWt in small communities[2]. At present nuclear district heating appears to be most promising in countries which already have heat distribution networks.

The concern of leakage of radioactivity into the heating network has been taken care of by intermediate heat transfer loops operating at higher pressures than the steam loop from the turbines, and by constant monitoring. The safe and reliable operation of several district heating networks (e.g., in Bulgaria, Hungary, Slovakia, Russia, Ukraine and Switzerland) has proved their effectiveness.

Table VI from IAEA Tecdoc 1056 (1998), as improved in ref 2, shows the world experience of nuclear reactors in commercial district heating. Out of these 46 reactors, only two in China and Russia were used for the sole purpose of district heating. Over twenty plants in Russia and the Bruce CANDU plants in Canada were used for electricity generation and to provide heat for both process heat and district heating. Steam from Bruce A plant was used for the heavy water production plant and for the nearby agricultural and industrial complex. One also notes that of the many existing and proposed designs of nuclear power systems for district heating, the majority are based on the use of water reactor technology.

TABLE VI. OPERATING NUCLEAR REACTORS WITH HEAT APPLICATIONS[‡]

Country	Plant type or name	Location	Application	Start of operation	Power (Mwe net)	Heat output (MWth)
Bulgaria	WWER-1000	Kozloduy 5 - 6	E, DH	1987,91	2x953	2x20
Canada	CANDU	Bruce Energy Centre[§], Ontario	E, P, DH	1977-87	750-860	79
China	NHR-5	Beijing	DH	1989	0	5
Hungary	WWER	Paks 2, 3, 4	E, DH	1984-87	3x433	3x30
Russia	Research reactor	Obninsk	DH	1954	0	10-20
Russia	RBMK	Bilibino 1 - 4	E, DH	1974-81	4x11	4x25
Russia	WWER	Novovoronezh – 3,4[**]	E, P, DH	1971, 72	2x385	2x32.5
Russia	WWER-1000	Novovoronezh – 5	E, P	1980	950	
Russia	WWER-1000	Balakovo 1-4	E, DH	1986-93	4x950	4x200
Russia	WWER-1000	Kalinin 1-2	E, P, DH	1984 –86	2x950	2x80
Russia	WWER-440	Kola 1 - 4	E, P, DH	1973-84	4x411	55
Russia	BN-600	Belojarsk-3	E, P, DH	1981	560	170
Russia	RBMK-1000	Leningrad 1 -4	E, P, DH	1974-81	4x925	4x25
Russia	RBMK-1000	Kursk 1- 4	E, P, DH	1977-86	4x925	127.5, 3x175
Russia	RBMK-1000	Smolensk	E, P, DH	1983-1990	3x925	3x173
Slovakia	WWER	Bohunice-3, 4	E, DH	1984 1985	2x408	2x240
Switzerland	PWR	Beznau 1, 2	E, DH	1969-71	2x365	2x80
Ukraine	WWER	Rovno 1, 2	E, DH	1980-81	381, 376	2x58
Ukraine	WWER	Rovno 3	E, DH	1987	950	233
Ukraine	WWER-1000	South Ukraine 1-3	E, DH	1983-89	3x950	2x151 1x232

[‡] E, P and DH stand for electricity, process heat and district heating.

[§] Bruce A reactors are currently laid up; it is expected to start up in 2003.

[**] Unit 1 was taken out of operation in 1988, unit 2 in 1990.

The market potential for district heating has been estimated[2] to be between 340GWt and 7600GWt. Table VI shows that nuclear power provides only about 4.4 GWt. Since there are various sources for heat such as oil, coal and natural gas, unless nuclear power is economical in the open market, it cannot make a big dent in commercialising nuclear district heating. The scaling effect is also important for nuclear district heating as it is more expensive at lower power. At 500 MWt and above the nuclear option shows good chances to be competitive even at higher discount rates[2]. Perhaps as nuclear power receives more acceptance from the public and nuclear electricity becomes competitive with other sources of electricity, nuclear district heating will also become more common.

4. INDUSTRIAL PROCESS HEAT APPLICATIONS

There are five primary areas of industrial heat applications: food processing, paper industry, chemical industry, petroleum and coal processing, and primary metal industries. Relative use of process heat in these industries is shown in Table VII for two developed countries, the U.S. (1994) and Germany (1989).

TABLE VII. INDUSTRIAL USE OF PROCESS HEAT IN THE U.S. AND GERMANY[2]

Industry	Percentage use of process heat in	
	Germany	USA
Food and products	19	5
Paper and products	18	12
Chemical	33	25
Petroleum and coal processing	8	33
Primary metal industries	10	12
Other	12	13

Industrial process heat is mainly used in the form of steam at appropriate temperature and pressure conditions. The demand is usually steady and there is no seasonal variation and hence quite suitable for supply by nuclear power. The only problem is that the source must be nearby as heat loss in transit is considerable.

There are three cases of commercial use of nuclear process heat in Canada, Germany and Switzerland. This is shown in Table VIII. The application to the heavy water production facility in Bruce, Canada was the largest use of nuclear process heat and it has operated very successfully for over 20 years. The six other industries the Bruce complex provided process heat were plastic film manufacturing, ethanol plant, apple juice concentration plant, alfalfa dehydration, cubing and pelletizing plant, a greenhouse, and an agricultural research facility.

TABLE VIII. NUCLEAR PLANTS PROVIDING COMMERCIAL PROCESS HEAT[1]

Country	Plant Name	Start of Operation		Power MWe	Heat Delivery MWt	Interface Temp C Feed/ Return	Distance to Industry Km	Application
		Reactor	Heat					
Switzerland	Goesgen PWR	1979	1979	970	25	220/100	1.75	Cardboard factory
Canada[a]	Bruce-A CANDU	1977-87	1981	4x848 4x860	5350		Nearby industrial complex	Heavy water production and 6 other industries
Germany	Stade PWR	1983		640	30	190/100	1.5	Salt refinery

[a] Unit 2 of Bruce A was taken out of service in 1995, units 1,3 and 4 were taken out of service in 1998. They are expected to start up in 2003.

The total potential market of industrial process heat is large and of the same order of magnitude as district heating. It is estimated to be between 240 GWt and 2900 GWt[2]. However, the demand in terms of size varies; some 50% of the users need less than 10 MWt, 40% need sizes from 10 to 50 MWt, and only 10% need sizes greater than 50 MWt[3]. Very few need a large amount of process heat as in the Bruce example in Canada. The market is also very competitive as small fossil fuel units can provide the needed steam.

5. HIGH TEMPERATURE APPLICATIONS: FUEL SYNTHESIS

As shown in Table II, liquid metal and gas-cooled reactors can generate very high temperatures, which could be used to create new synthetic fuels for energy. This will be an innovative application of nuclear energy and can considerably expand its use. This is because the transportation sector is responsible for about a quarter of the total energy use and almost 99% of this is currently supplied by organic fuel. Nuclear power can penetrate this large market through use of electric cars and production of synthetic fuels such as methanol, ethanol and their derivatives; nuclear power can also be used for coal gasification, oil extraction and hydrogen production. All of these are being seriously considered in the 21st century. However, the infrastructure for use of these fuels needs to be created first, particularly in the case of environmentally ideal hydrogen fuel.

Coal gasification (i.e., conversion of solid coal into a gaseous fuel like the natural gas) requires very high temperatures but could be practical because the infrastructure for use of natural gas already exists, and there are vast deposits of coal in the world and this conversion can remove environmental pollutants such as particulates like sulphur-dioxide and nitrogen oxides. The efficiency of coal fire plants will also be improved by coal gasification. The process of coal gasification is, however, quite energy intensive; one unit of gasified coal may require about 1.7 units of energy in solid coal[13]. High temperature gas-cooled reactors can play a role here.

Another possible use of nuclear energy is for oil extraction from tar and oil sands and for enhanced oil recovery operations, particularly from depleted oil deposits. Canada and Venezuela have large resources of oil and tar sands. Steam injection is used for these extraction applications and steam can also be used for processing the oil after the extraction.

The feasibility of nuclear application for production of more organic fuel really depends on the economics. So long as fossil fuel, particularly oil and gas, are available at low prices, nuclear will not be a preferable option. Only dual use, where nuclear electricity can compete in the market, could make these applications worthwhile.

Hydrogen economy has received renewed interest because of new developments in HTGR technologies. Several paths to hydrogen production are being considered: decomposition and gasification of fossil fuel such as steam reforming of methane and carbon dioxide reforming of methane; and decomposition of water, namely, low-temperature electrolysis, and combination of electricity and heat for high temperature electrolysis. These are briefly described below.

A. Steam Reforming of Methane

In this method Methane (CH_4), a main component of natural gas, and water react at temperatures of 600 – 800 C to produce hydrogen and carbon monoxide and dioxide. The steam reforming system can be easily coupled to a HTGR, which can provide the necessary heat and high temperature. Considerable R&D work has been carried out in Germany for the steam reforming of methane including performing experiments in a pilot plant, EVA-I and EVA-II. Currently work is in progress in JAERI for the HTTR[14], in China for the HTR-10[15] and in Russia.

B. CO_2 Reforming of Methane

The basic CH_4 and CO_2 reaction for this process (with no addition of steam) produces CO and hydrogen. The reforming process requires high temperature (800 – 900 C) and high energy input, both of which can be provided by HTGRs. The generated CO and H_2 mixture (syngas) can be used directly as fuel for electricity generation (e.g., by fuel cells).

C. Thermo-chemical Water Splitting

One mechanism that is being considered seriously for hydrogen production is thermo-chemical water splitting by the Iodine-Sulfur (IS) process. The IS process was originally proposed by the General Atomic Company in early 1970's and is very promising because it involves only a few reaction steps. In this process Hydrogen-Iodide (HI) is produced by a cyclic chemical reaction chain utilizing Iodine, sulfur-dioxide and water; HI is then decomposed to produce hydrogen, releasing Iodine to the chemical reaction chain. Sulfuric acid, H_2SO_4, is generated in the process, which is vaporised and decomposed at a temperature of about 800 to 900 C to sulfur-dioxide, water and oxygen. The oxygen is released and sulfur-dioxide and water is returned to the reaction cycle. Laboratory scale experiments at Japan Atomic Energy Research Institute have demonstrated the feasibility of the IS process with continuous generation of hydrogen from water with recycling of the process material. An energy efficiency of 47% has been achieved in this process[16].

D. Electrolysis

Water electrolysis at ambient pressure and temperature of 70 – 90 C is a common method for production of high purity hydrogen. However, it has been found that the demand for electricity decreases with increase of temperature. That is the electric energy required is much reduced for the electrolysis of steam at higher temperatures (800 C and above). High temperature electrolysis is a reverse reaction of the Solid-oxide Fuel Cell, where water is decomposed in the solid polymer electrolyte to hydrogen and oxygen. This method is at an early stage of development[14].

Conclusion

There are several possibilities for direct utilization of heat from nuclear reactors. Nuclear desalination, district heating and industrial process heat are examples where this has been done, and these non-electric applications of nuclear power can be expanded in the future. It is also important to note that a wide range of temperatures, for low to high temperature applications, can be tailored for specific uses by different reactor types. Table IX shows the status of projects in several countries for non-electric applications of nuclear energy. The proposed applications are primarily for dual-purpose use but dedicated heating reactors are also being developed in China and Russia. Innovative applications are being explored with gas-cooled reactors because of their high temperatures. High temperature applications of nuclear energy, particularly for production of new fuel such as hydrogen, are in the laboratory stage now but have a great potential for the future[3].

Cost-effectiveness is in general a crucial issue for non-electric applications of nuclear power. As nuclear power captures a larger share of the electricity market, the non-electric applications will also flourish. Until now, the non-electric applications are only a very small part of power production. For some applications, however, close proximity of the power plant to a population centre is needed (to reduce energy and/or product transmission losses) and this requires further public acceptance. Some large applications also require the development of infrastructure - heat-distribution networks for district heating and water distribution systems (water pipes and pumps) for fresh water. Many countries are exploring these possibilities of nuclear power. As mentioned in the text, there is a large market for non-electric applications of nuclear energy and it is hoped that someday this potential will be realized.

TABLE IX. PROSPECTIVE NUCLEAR PROJECTS FOR NON-ELECTRIC APPLICATIONS

Country	Plant type or site	Location	Application[††]	Project status	Power, MW(e)	Heat output, MW(th)
Bulgaria	WWER	Belene	E, DH	Design	2x1000	400
China	NHR-200	Daqing City	DH	Dormant	0	200
China	HTR-10	Tsinghua University, Beijing	Electricity/ high temp. applications	Achieved criticality in Dec. 2000		10
Japan	HTTR	Oarai (JAERI)	High temp. process heat	Operating	0	30
Russia	RUTA	Apatity	DH / Air conditioning	Design	0	4x55
Russia	RUTA	Obninsk	DH	Design	0	55
Russia	ATEC-200	-	E, DH	Design	50-180	70-40
Russia	VGM ./ GT-MHR	-	P	Design	-	600
Russia	KLT-40	Floating	E, DH & Desalination	Regulatory process completed	35	150
Russia	AST-500	Voronez	DH	Construction suspended	0	500
Russia	AST-500	Seversk	DH	Completed feasibility study, approval of the project by State regulatory authority is nearing completion	0	500

[††] E: Electricity (Power), P: Steam supply for process heat, DH: Steam/Hot water supply for heating.

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