Appendix I
DESIGN AND DEVELOPMENT STATUS OF SMALL AND MEDIUM REACTORS 1995

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1. INTRODUCTION

The increased confidence in reactor technology coupled with the argument about the economics of scale have led most of the industrialized countries to design progressively large reactors up to 1600 MWe power capacity blocks. This, as a result has shifted all earlier designs to the small or medium size reactors. Moreover, a medium size plant capacity has shifted to include 700 MWe power units. This allows the SMR range to be suitable to many developing as well as some of the developed countries. Small reactors are being used for heat applications and power generation on a smaller scale in remote areas and for developmental purposes. For the purpose of this technical report, small reactors has been taken as reactors with a thermal power of 400 MWth or less.

Taking as a rule of thum~~p~~b power units to be 10% of the total grid size, many utilities worldwide could only support a small or mid size plant. Site specific constraint such as the absence of adequate cooling water and the national technological level in many developing countries make the SMR range most suited for power application. Remote areas, isolated from the national grid such as the case in Russia and many remote islands in the South East region of Asia provide suitable condition for smaller power units that could run economically even in the range of 40-100 MWe or less. The assessment of the world market projection for seawater desalination carried out by the IAEA as part of the options identification programme concluded that a sufficient large demand in the years 2015 and beyond will support the installation of sizable desalination capacities. A reasonable part of this, is in the size ranges of 50,000 to 100,000 m^3/d. This range corresponds to 25-50 MWe net power output. The most convenient size of the reactor would be in the small reactor range, both if the reactor power be used totally for desalination or if the reactor is to operate in a cogeneration mode.

A small reactor could have simpler safety systems due to the larger margins, making the implementation of passive safety easier to engineer. Small reactors have also been an important vehicle for the development of new designs.

The need for smaller size reactors in many parts of the world has made the potential market for such system to look large and has encouraged the manufacturers to continue their efforts. In spite of the fact, that the market has turned out to be over estimated, the number of reactors in the SMR range in operation or under construction closely matches the case for large units (Fig.1). These factors have made the SMR area getting a wide attention worldwide. In this paper the main design features and market potential of the SMRs in all three reactors lines namely WCRs, GCRs and LMRs will be discussed. Design and development efforts worldwide will be highlighted.

Design features

Looking at the currently active reactor design concepts, several common basic features could be summarized as follows:

- Low power density.
- simplified configuration.
- Utilization of natural driving forces (passivity).
- Enhanced overall plant arrangement.
- Modular construction and fabrication.
- Reliance on proven technology.
- Low radiation exposure dose.

Light water reactors

These basic design features have been used to develop different design, concepts in the light water reactor (LWR) area that are present today. A large number of these concepts are safety driven. Innovation in residual heat removal, make up systems and the elimination of large LOCA by design are some aspects worth noting. New concepts and the overall simplification of SMR systems are an area that deserve discussion.

Makeup systems

Gravity fed accumulators, steam injectors and pressurized makeup tanks have many variants in the different designs. Accumulators are generally designed for large volume make up water and usually operated under N_2 pressure in assuring high water flow into the Reactor Pressure Vessel (RPV). Makeup tanks are usually operated at the full primary circuit pressure and water injection is gravity driven. Steam injectors are also used. In this case

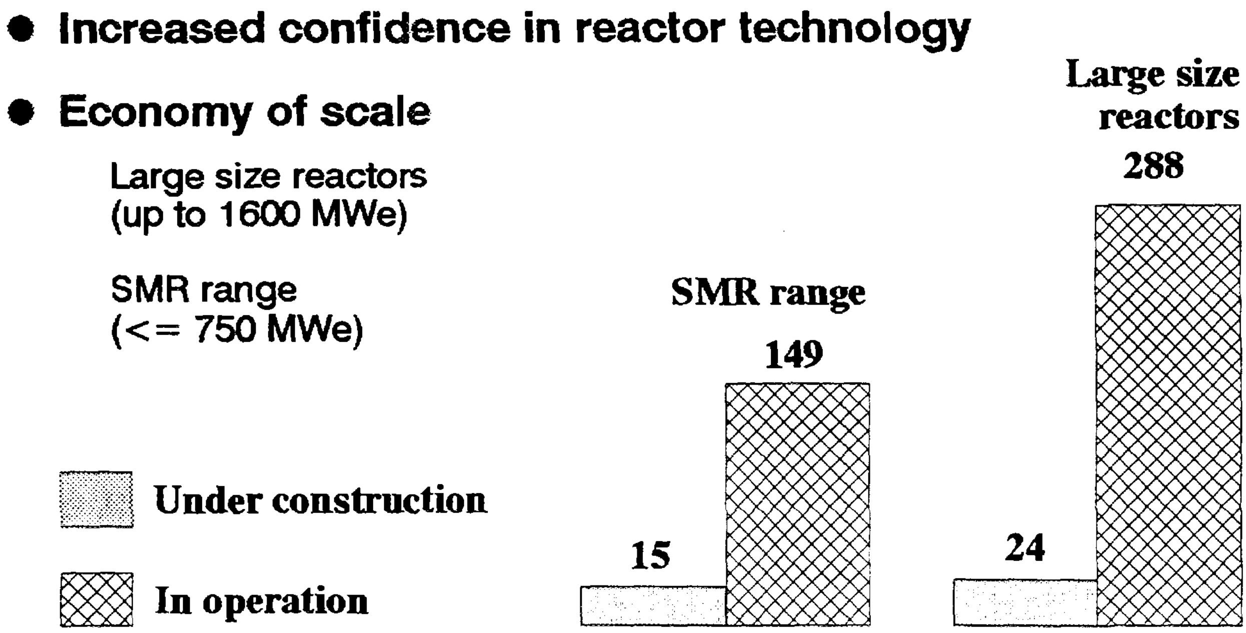


FIG. 1. SMR Design and development status.

steam is used to inject water from a water storage tank. The technique is as old as the steam locomotive industry but is needed here at a much higher pressure and hence their reliability has to be demonstrated. Experimental programmes to test their effectiveness are underway.

Residual heat removal systems

Residual heat can be removed from the primary or secondary circuit and from the containment. There is, thus scope for diversity without being extravagant in the complexity of the systems. There are normally two types of residual heat removal systems (RHRS); systems used during normal operation, and those provided in the safety grade systems. Almost all the SMRs go for passive RHR systems.

Residual heat is usually removed from the primary coolant via a heat exchanger which transfer the heat via natural convection to an external heat exchanger in a larger water storage tank or directly to the atmosphere. In most cases valve operation is required to put the system in operation, but in a limited cases the system is designed for a continuous operation which has a significant effect on efficiency. This has partially overcome by extracting some of the heat in a feedheater.

An other alternative used in some designs is rechanneling part of the primary water to an auxiliary heat exchanger, as it is the case in the AP600 design.

In integral reactor designs, steam generators within the RPV are made use of as a convenient route for residual heat removal. Valve movement in this case is inevitable and hence some redundancy must be established.

Additionally, a bleed and a make-up system could be utilized to remove residual heat from either the primary or secondary circuit. The AST500 and SIR designs make use of such alternative.

Innovation has been exercised by residual heat removal walls of the containment. Steam from the reactor is condensed directly on the walls of the containment or by means of a heat exchanger arrangement. The latter system allows for a full double containment as required in some countries. For practical reason, direct heat transfer through the containment puts a limit on the reactor power level that could be attained with such arrangement. This limits such possibility to the SMR range.

Loss of coolant accident

The first line of defence in depth is prevention. Prevention could start in the design stage. Pipe connection would always run as part of the primary and secondary circuit but if they are kept small in number and size the possibility and consequence of a LOCA would be substantially reduced. BWRs by their basic design have such features. In integrated PWRs the entire primary circuit is enclosed in the RPV with the exception of the CVCS and makeup water piping, achieving the same objective.

Second line of defence is to ensure that core uncovery does not take place. the main feature is to avoid any penetrations in the RPV well above the core level by several meters to provide coolant inventory for boil off and relax the need for fast makeup water in the large quantity.

The other approach is to provide an outer vessel which is either permanently flooded (PIUS concept) or can readily be flooded (guard vessel). The PIUS concept provide for the most innovative design in the SMR range. The primary coolant is isolated from the highly boronated water in the out vessel by hydraulic seals. In case of any significant disturbance to the normal flow the boronated water would always enter the primary system providing large water inventory and causing the scram of the reactor. Other design that used the PIUS concept are the Italian ISIS and the Japanese ISER designs.

Small LOCA in older design was caused by pump seal failure. This has been eliminated by selection of canned rotor pumps. These pumps have a considerable operational experience. If the circulating pumps position is selected in the RPV bottom area to avoid cavitation, their penetration has to be designed to the same standard as the RPV head with regard to integrity and inspectability.

Heavy water reactors

Several reactor design have appeared in the SMR range that use Heavy Water as a moderator (e.g. CANDU 3, CANDU 6, PHWR 500, PHWR 220). The main features of this technology line is:

- The use of natural uranium
- On-power type of refueling
- Very low access of reactivity
- No RPV, but rather pressure tube is used.

In addition to these features, all designs allow for the passive residual heat removal in case of loss of power. CANDU 3 emphasized the assurance of high capacity factor, the maximization of component life and the easy replacement of components.

Gas cooled reactors

The design features of the gas-cooled reactors have centered on the use of ceramic coated particle fuel, and the use of an inert gas as a coolant. The fuel particles are uranium oxide or carbide approximately 0.5 mm in diameter with a multiple layer coating of pyrolitic carbon and silicon carbide forming a micropressure vessel around the individual fuel particle that could withstand around 800 bar of internal pressure. The fuel particles are bound together in a graphite matrix capable to retain fission products up to 1600°C and provide high temperature gas outlet. The operating temperature restriction is mainly due to the limitation on the structural material. New materials for heat transfer systems capable of operating at high temperatures (e.g. 900°C) make them attractive for direct use in gas turbine and high heat process applications. The coolant being an inert gas eliminates any chemical or energetic reaction with core structure.

These features combined with a negative temperature coefficient of reactivity, large heat capacity of the graphite and the large design margins make the reactor safety extremely difficult to challenge.

The HTGR technology line utilizes complete passive system for RHR and shutdown. Residual heat is taken away by radiator surrounding the reactor pressure vessel utilizing natural circulation. Shutdown is accomplished by simply dropping small absorber spheres by gravity force.

Liquid metal reactors

The main design features of this line of technology is the low operating pressure due to the high boiling temperature and high conductivity of the coolant and the ability of the coolant to absorb the heat with insignificant moderation.

Small fast reactors can have totally passive safety systems. The main characteristics of this design are the metal fuel and sodium coolant.

Currently there are four modular small or medium-sized, liquid metal reactors. The Advanced Liquid Metal Reactor (ALMR) former (PRISM), the Modular Double Pool Reactor, the 4S (Super, Safe, Small and Simple) and the BMN-170.

2. DEDICATED NUCLEAR HEATING PLANTS (NHP)

The power range of nuclear heating reactors is generally lower than SMR power reactors. They are rated from about 2 to 500 MWth. Apart from the high temperature reactors, their outlet temperature is aimed mainly at district heating or sea water desalination and does not exceed 130°C. This corresponds to a primary circuit temperature of around 200°C, and a power density ranging from 2 to 60 kW/l.

The smaller size and lower pressure resulting from these requirement leads to simplification of the overall design and allows for the maximum utilization of natural processes. Simplifications have been achieved through a less massive RPV, through integration of the primary circuit in the RPV, and in the safety systems and containment. Further simplifications have been made in the use of natural circulation for normal heat removal (made possible by the large safety margins in the NHP design) and by the use of passive safety systems.

Over a dozen reactor designs are known worldwide, most of which have originated in developing Member States. The economics of these reactors, however, can only be justified in remote regions isolated from a national grid. Only a few of the concepts have been constructed (e.g. AST-500 in Russia, HR5 in China and SLOWPOKE in Canada). As a result there is only little operational experience.

Simplification

Plant simplification imply simplification of system arrangement, operation, maintenance, inspection, and quality assurance. Modular isolation and prefabrication are key design features of the SMR systems. SMRs of the new generation with no exception lay great emphasis on simplification. The use of passive systems leads also to simplification. This is mainly due to the elimination of multiple redundancies and safety grade power supplies. Integral designs eliminate large pipe penetrations leading to further simplification. Hydraulic drive mechanism provided further simplification for some designs (NH200).

Most designs have reduced the number of components (valves, cables, piping) by as high as 80% in the most favourable conditions. Digital electronics and distributed systems provided further simplification and increased reliability.

Traditional control rod drives require a lot of space either above or below the core. There are possibilities to use liquid absorber materials, which do not require the space for rod drives and for in vessel storage when withdrawn. There have also been designs for in vessel mechanical drives (PSR, MRX, HR 200). These eliminate the need to consider control rod ejection which is one of the main, but unlikely, reactivity accident initiators. A more radical solution is in the JAERI SPWR design where liquid filled tubes are used instead of control rods.

The elimination of large primary circuit pipes in integral PWRs allows an easing of the containment specification. Pressure suppression systems for PWRs become feasible and several versions have been proposed.

There are very significant developments in instrumentation and control systems allowing simplification and an increase in reliability at the same time. Many proposals use process computers and digital electronics leading to a complete redesign of the architecture of the control system.

The use of passive safety systems leads directly to simplification in design since it eliminates the need for multiple redundant safety systems with their redundant safety grade power supplies. A system which relies only on gravity for its operation has no problem about the availability of its power supplies and has a reliability determined only by the integrity of its piping and flow channels.

Passive safety

The passive safety approach deserves a separate mention since it is a feature of many SMR designs. The original incentive was to produce designs which could cope with any accident initiating event coupled with the failure of all engineered safety systems. There are thus different degrees of passivity and the recent IAEA document on reactor terminology has gone to some lengths to include all the different types of system for which their designers claim passivity [5].

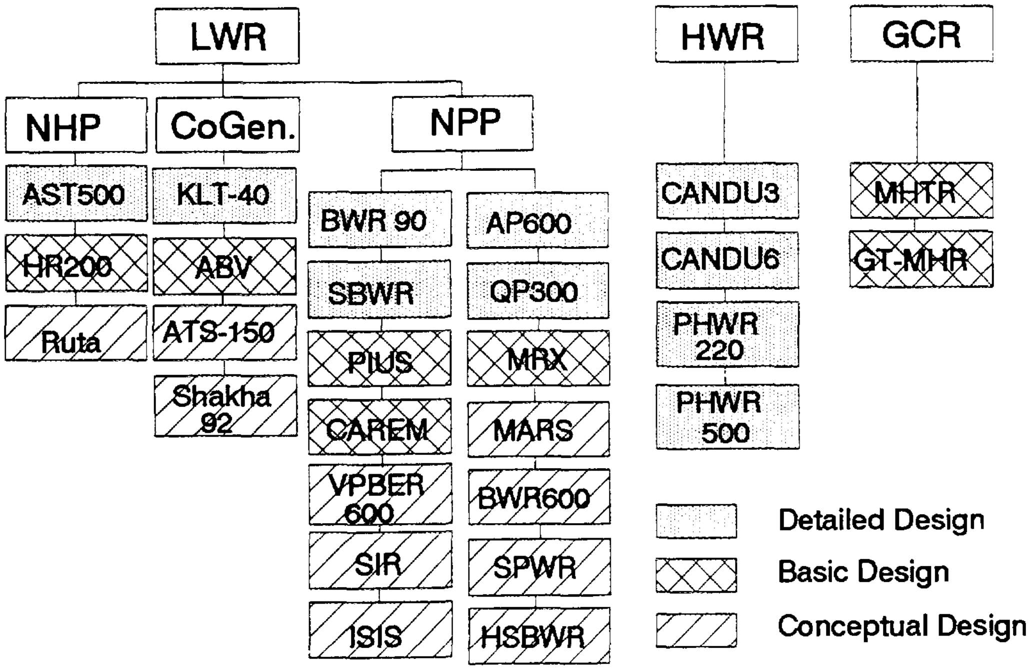
Small and medium size reactors have utilized the reliance on passive principles to attain safety functions. In some cases complete reliance on passive safety systems has been the main incentive for a number of designs (e.g. AP600, PIUS, MHTGR). One of the main design objectives is to be able to deal with any accident initiating event coupled with the failure of the engineered safety systems utilizing solely natural process such as gravity driven and natural convection. This would need no operator intervention for a long, may be indefinite, period. Some reactors have achieved this in their design with their safety systems being passive both in initiation and in operation. Others have relayed on stored energy (e.g. batteries, springs) for process initiation. The important issue here is not the degree of passivity but rather the reliability of such systems and the possible need for redundancy. Experimental programmes for verification of these issues are underway.

SMR development

Nuclear energy is playing an important role in supplying a significant portion of the world electricity demand. In spite of the slowdown or stoppage of nuclear programmes in many countries in the last decade utilization of nuclear power is picking up momentum at various bases in South East Asia, Eastern Europe and the former Soviet Union.

Table 1 provide the main reactor designs in the SMR range being developed and their design status. It could be seen that the development effort worldwide is large with many

TABLE 1. SMR DESIGN STATUS



being in the detailed design stage and some are under construction (Table 2). Other prototype demonstration plants have either started operation or under construction (e.g. MONJU, 10 MWt, HTGR, HR5 in China).

2.1. The SMR market

The current growth of population and energy demand is dominated by developing countries. There are many places and applications where this increased demand will be best met by power plants in the SMR range, due to a small grid system or for application in a remote area or for a special purpose.

The world primary energy consumption amounts to well over 300,000 Peta joules and over half of that is used as hot water, steam and heat. Only a few nuclear power plants are being used for heat applications (district heating, heat for industrial processes, and seawater desalination). Potential nuclear heat applications include enhanced oil recovery, petroleum refining, petrochemical industries, and methanol production from hard coal. The need for potable water in some parts of the world is large, vital for sustaining development, and ever increasing. Clearly nuclear heat and power production could play a major and important role.

Nuclear power at present is used mainly for electrical power generation which only forms 30% of the energy market. There have been numerous studies on the use of SMRs for heat applications rather than electrical generation and some of these studies have shown the SMR option to be viable both technically and economically [2]. Future expansion of nuclear application, beside addressing large power generation demand, may also come from more spread energy market involving smaller units for process heat applications and small scale power generation in remote areas.

2.1.2. SMR projects

With such a range of possible applications in many different parts of the world, a large number of different R & D and design projects have been set up. Fig 1 lists those for which descriptions have been submitted to the latest IAEA review on the subject and indicates the status of their development. LWRs, HWRs, GCRs and sodium cooled reactors all have active development work in various Member States.

Over the past 30 years there have been many market surveys for SMRs. They have shown a potential for sales of a large number of reactors before the turn of the century. These estimates of the market have turned out to be grossly overoptimistic but have encouraged developers to continue their efforts. In spite of a moderate response from the market, there is still a very large development effort continuing but few of the advanced SMR designs have yet been in operation to demonstrate their capabilities. Indeed, few of them have been funded through the detailed design stage to make them ready for construction. They do, however, present a variety of solutions to the problems of reactor design for future designers to draw on and to give an impression to purchasers of the capabilities of current designs, which could be developed to meet their needs. The Agency is currently involved in a study on the market potential of SMRs which is expected to be concluded in 1997.

There is thus a gap between the designs available but not built, and their exploitation in what appears to be a potentially large market.

2.1.3. Bridging the gap

Possible ways of bridging the gap would be for vendors to collaborate on one design to spread the design and development costs and for users to collaborate to define an SMR requirements document for particular applications. There have been some notable vendor collaborations in industrialized countries demonstrating that this is a possible way forward. Requirements documents have been produced for power generation and requirements have been harmonized on a regional basis (Asia, Eastern Europe, Western Europe and North America). Developing Member States having similar technological and financial circumstances could establish their version of requirements for an identified market (e.g. desalination). Such requirements could be taken up in some of the developing projects to enhance their prospects for constructions. An other important aspect to the deployment of nuclear power in developing countries is the development of the required manpower and infrastructure for a successful programme.

2.2. Incentives for development

Small and medium size reactor development has many incentives; some are economic others are safety related. The motivation for these developments has included the need to enhance public acceptance of nuclear power. The simplification of designs should improve the transparency of their reactor safety. Another incentive to SMR development has been its suitability for the implementation of new design approaches. Innovative and evolutionary designs with novel features have been implemented in the SMR range. A passive safety approach has so far been the technology of small and medium reactors. SMRs have particular characteristics which can enable them to be economically viable in spite of losing the advantage of the economics of scale.

The incentives for the development of SMRs can be summarized as follows:

- Simpler design,

  An SMR can be modularised more easily and constructed in a shorter time than larger plants, thus reducing constructions costs (including interest during construction) and generating earlier revenues.

- Increased safety margins leading to a longer grace period,

  Passive safety features simplify the design and attain the required safety objective in a different way compared to large plants with more active safety systems. This could reduce cost and facilitate the presentation of the safety of the reactor to both regulatory authorities and the public.

- Lower severe core melt frequency and minimum accident consequences.

- Better match to grid requirements,

  SMRs can provide a better match to small grids or to a slow growth of energy demand. Taking into consideration the potable water demand and the corresponding energy requirement, a SMR would be a suitable candidate for a developing country starting its nuclear programme.

- Better use of nuclear industry infrastructure and manpower skills in countries with small nuclear programmes.

  One 600 MWe unit every 2 years is preferable to one 1200 MWe unit every 4 years.

- SMRs could open up energy markets,

  SMRs can be used for process heat, desalination, district heating and enhanced oil extraction as well as power generation.

- Lower financial risk due to:

  lower financing requirements per unit,
  shorter and better predictable construction schedule.

2.3. Objectives and requirements for SMRs

Development or deployment of SMRs could take place in a programme under the following general objectives:

1. The size of reactor is appropriate to a geographical location, distribution network or application.
2. It should be economic within the constraints of the other objectives.
3. It must be demonstrably safe and licensable.

These general objectives are applicable to reactors of any size but there are particular aspects of SMRs which help in meeting them.

1. Size. SMRs are appropriate for remote regions with limited load. They are appropriate for utilities with small grid systems. They are appropriate for some dedicated applications such as desalination, district heating or process heat possibly in a co-generation mode.

2. Economics. SMR designs all aim to simplify the design to reduce costs and offset to some extent the economies of scale. Modularisation allows a greater element of factory construction and assembly and is generally less expensive than work on site. It leads to shorter construction times and savings in interest during construction. The reduced capital requirements compared with large plants may well be attractive to purchasers.
3. Safety. Most SMRs make extensive use of inherent safety features and passive safety systems. Such systems are appropriate to SMRs and are harder, if not impossible, to engineer on large reactors. They tend to be simpler than active systems resulting in a simpler safety case and easing the problems of public acceptability.

While objectives provide for general and long-term applicable targets for nuclear reactors of present and future designs, requirements provide more specific, clear and complete statements by utilities in a given country. The requirements are usually grounded on well proven technology and long experience of commercial operation. The design requirements usually take into consideration problems of the past and incorporate new features assuring simple, robust, and more forgiving designs. They also provide for a common ground for regulators and vendors on licensing issues. Well defined requirements agreed upon by regulators, vendors and utilities provide for investor confidence. The design requirements usually cover the whole plant (i.e. NSSS, BoP, safety systems etc.) and provide clear specifications with regard to performance, maintainability and plant economics. Taking into consideration infrastructure and experience, requirements in most developing countries and some industrialized countries are expected to be easily fulfilled by a small or medium reactor.

3. PROGRAMMES FOR SMR DEVELOPMENT

3.1. Current activities in Member States

Nuclear energy plays an important role in supplying a significant portion of the world electricity demand. Reactor generated heat has been utilized in several parts of the world for district heating, process heat application, and seawater desalination. It should be noted here that over 50% of the world energy demand is utilized for either hot water or steam production. Such processes could be carried out more efficiently and cleanly utilizing nuclear energy.

Some South and East Asian countries believe strongly that nuclear power will be a principle source of energy for many years to come. Small and medium reactors form a major part of this activity. The People's Republic of China has a well developed nuclear capability having designed, constructed and operated nuclear reactors. A 300 MWe PWR (QP300) has been in operation for three years and two 600 MWe reactors are under detailed design and site preparation. Longer term plans call for development of a 600 MWe passive reactor (AC600). A 5 MWt integrated water cooled reactor has been built and operated for five winter seasons (since 1989) for district heating. Another purpose of the 5 MW reactor is the development work for other applications such as desalination. Construction of a 200 MWt demonstration heating reactor has been started aiming at start of operation by the year 1998. A 10 MWt high temperature gas cooled reactor for process application is also under construction.

India has adopted a prime policy target of self reliance in nuclear power development, based on heavy water moderated reactors. Five units of the 220 MWe PHWR type are under construction and all are expected to be in operation by the year 1997. An additional four units of the same type and an extra four units of a scaled up 500 MWe type are planned.

Japan has a preference for large reactors on the available sites to maximize the power output from them. There is a very strong and diverse programme of reactor development supported by the big industrial companies, by the national laboratories and by the universities. At least seven different designs are currently being worked on in the SMR range; namely SPWR, MRX, MS 300/600, HSBWR, MDP and 4S. SPWR and the marine reactor MRX are integrated PWRs. The MS series are simplified PWRs. HSBWR is a simplified BWR. MDP, 4S and RAPID are small sodium-cooled fast reactors. Preliminary investigations have shown a high level of safety, operability and maintainability. The economics of these systems are promising and they are expected to form part of Japan's next generation of reactors.

Japan has also a development programme where gas cooled reactors in the small and medium size range are under development. A High Temperature Engineering Test Reactor (HTTR 30 MWt) has been under construction since 1991 at Oarai.

Korea has ten PWRs and one PHWR in operation and has an ambitious programme for the further development of nuclear power. Most of the existing plants are of the large PWR type, but, since April 1984, there has been a policy to install medium size PHWR (~ 700 MWe) to diversify supply and operation. One PHWR is operating, another is under construction and two more are in the stage of seeking a construction permit. In addition, a relatively small 330 MW(th) integral reactor is also currently under development for a cogenaration purpose.

Indonesia has a very rapid growth of population spread over 13,000 large and small islands. There is a clear future potential for reactors in the SMR range. However, the main island has over half the current population and could take a large station; a feasibility study covering this and other aspects of Indonesia's possible nuclear programme has been undertaken. The outcome is in favour of the nuclear power option. 7000 MWe of nuclear capacity is being considered up to the year 2015. Optimal plant size is being looked at and a number of 600 to 900 MWe units are being considered. Indonesia has deposits of tar sands for which extraction based on nuclear heat using HTGRs is being investigated. A programme on public acceptance is being executed.

Thailand has just started a feasibility study on the construction of a nuclear power plant.

The current Russian programme is largely based on 1000 MWe units but the 500-600 MW range is well represented in the development programme. Two units of 600 MWe each are planned in the Far East region of the country for the period 2000-2010. Two others in Karel'ska are planned for the same period.

Russia is a country with a clear scope for the deployment of smaller plants due to its huge land mass with remote communities living in areas with harsh winters. The nuclear energy option seems to have favourable economics compared to conventional sources for application in remote areas, especially for domestic heating. Several reactors of small size (10-30 MW) are planned for construction around the year 2000.

Eastern Europe has VVER units of the 440 MWe size but for the future larger units are considered. In Western Europe, most utilities have opted for large nuclear power plant (1000-1500 MWe) if they have opted for nuclear at all. On the basis of several different national development programmes on SMRs, many innovations using a wide variety of coolants, fuel, containments and safety features have been worked out. More recently, SMR-specific development effort in Western Europe has decreased because of reductions in governmental funding.

In the USA, the AP600 in the SMR range is being supported and aggressively marketed worldwide, in addition to a large reactor design (ABWR). In Canada a perceived need for a simpler, cheaper reactor which could be more easily demonstrated to the public as safe has led to the development of a smaller version of the CANDU line. Design and safety requirements for the next generation of reactors have been identified both in Canada and in the USA by the utilities and governmental agencies. In North America, Medium Size Reactors are expected to supply a significant share of nuclear electricity in the future.

In Argentina the work on Atucha 2 (745 MWe PHWR) is continuing. Argentina has carried out a development effort for the design of a small pressurized water cooled reactor "CAREM". The system has a total power of 100 MWth and it is of the modular integrated type. The basic design of the system is complete and it is currently undergoing detailed design.

North African and Middle Eastern countries have identified a strong need both for electricity and for power for desalination and several of them are looking at the nuclear option. The reserves of fossil fuel are massive in some countries but others rely largely on imports. The water problem is compounded by low rainfall, a rising population with increasing expectations for its standard of living and by a lowering of the water table in the traditional sources under the desert sands. A study for the North African countries of the economic feasibility for nuclear desalination has been completed [3]. A feasibility study for a demonstration facility for seawater desalination in Morocco is expected to start in 1996. In Egypt, a feasibility study has been completed for a medium sized NPP[4].

TABLE 2. SMRs UNDER CONSTRUCTION

Country	Number of units	Name	Type	Power MWe (net)	Expected date of commissioning
Argentina	1	Atucha II	PWR	692 MWe	1998
India	4	PHWR 220	HWR	202 MWe	1998-1999
Republic of Korea	3		PHWR	650 MWe	1997-1998-1999
Pakistan	1	Chashnupp	PWR	300 MWe	1999
Romania	2		PHWR	650 MWe	1996-2002
Slovak Republic	4	Mochovce	PWR	388 MWe	???
Russian Federation	2	AST 500	PWR	500 MWth	1998

From information provided by Member States (see Table 2), it can be seen that several nuclear power plants in the SMR range are under construction around the world. Nuclear power investment on a worldwide basis has preferred large units due to the economy of scale, especially in the industrialized countries. This can be clearly seen from the number of nuclear power plants in operation today (Fig. 1). The number of units currently under construction in the SMR range is in the same range as that of the big power plants. These data show that SMRs could play an important role in many industrialized and developing countries.

Conclusions

Small and medium size reactor design and development is a very active area. The design work has made maximum use of simplification, modularization and prefabrication. No SMR design has not tried to make use of natural forces. The SMR range has been the main vehicle for innovative designs.

Small and medium sized reactors have good potentials for future deployment specially in developing countries both for power generation and process heat application.

Small and medium reactor systems provide an attractive option for a wide range of applications worldwide. The design approach and design characteristics of the SMRs with regard to size, economics and safety appear to provide favourable conditions. Specific requirements on these topics will provide a common ground for the suppliers and interested users to further the discussion on specific design requirements such as performance, operability, maintainability, reliability. For successful deployment, overall cost must be competitive with other alternatives, taken into consideration the main objectives.

Among existing reactor designs, the pressurized water reactor of the integral type seems to be well suited for a wide range of low power applications, including seawater desalination. Integral reactors using natural circulation of the primary coolant and utilizing passive safety systems appear to be technically capable of achieving a high degree of safety and reliability.

An important aspect to the introduction of nuclear power in a developing country is a well planned and executed programme on the development of the required infrastructure according to the objectives of the programme.

REFERENCES

[1] International Atomic Energy Agency The Design and Development Status of Small and Medium Reactor Systems 1995, IAEA-TECDOC-881,Vienna (1996).

[2] International Atomic Energy Agency Nuclear Applications for Steam and Hot Water Supply, IAEA-TECDOC-615, Vienna (1991).

[3] Feasibility Study of Nuclear Desalination as a possible source of low cost potable water in North Africa, IAEA study under publication.

[4] International Atomic Energy Agency, Case Study on the Flexibility of Small and Medium Reactor Power Plants in Egypt, IAEA-TECDOC-739 (1994)

[5] International Atomic Energy Agency, IAEA-TECDOC-626, Safety Related Terms for Advanced Nuclear Plants, 1991.